THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR KHASHAYAR HADIPOUR

TITLE OF THESIS **RECYCLING OF ASPHALT CONCRETE PAVEMENTS**

DEGREE FOR WHICH THESIS WAS PRESENTED MASTER OF SCIENCE IN CIVIL ENGINEERING

YEAR THIS DEGREE GRANTED FALL, 1983

THE UNIVERSITY OF ALBERTA

RECYCLING OF ASPHALT CONCRETE PAVEMENTS

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

FALL, 1983

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled **RECYCLING OF ASPHALT CONCRETE PAVEMENTS** submitted by KHASHAYAR HADIPOUR in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE IN CIVIL ENGINEERING.

ABSTRACT

Recycling of asphalt concrete pavements is a developing technology, resulting in cost savings, energy savings, and the conservation of natural resources. The purpose of this research is to investigate the application of this technology and consequently to promote its usage by providing improved design and construction techniques and recommendations. The research is mainly concerned with central plant hot mix recycling.

This study firstly presents a summary of various recycling categories and techniques and the factors to be considered in selection of recycling projects. This is followed by recommended procedures for controlling the quality of the recycled asphalt concrete pavements. A sequence of steps leading to a recycled mixture design is then presented.

The two 1982 recycling projects in Alberta, which were constructed during the course of this research, were the major contributors in improvement of design and construction techniques developed in this thesis.

To investigate the validity of recycling pertinent to cost and energy saving, an economic analysis is developed and a cost comparison between conventional and recycled asphalt concrete for the two Alberta recycling projects is carried out. It is proved that recycling will yield great savings in cost and natural resources without sacrificing the quality of the pavement.

The findings of this research indicate that recycled asphalt mixtures exhibit satisfactory engineering properties and pavement recycling can be the most desirable and cost effective alternative for pavement rehabilitation.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Professor K.O. Anderson for his guidance and support throughout the development of this thesis. Without his direction and suggestions the objectives of the research could not have been met.

The assistance and encouragement of Professors J.J. Bakker and S. Teply is gratefully appreciated.

I would like to thank Alberta Transportation for sponsoring this research. Special thanks to Messrs. R.C. White, D.P. Palsat, G.A. Berdahl, and K.A. Millions for their cooperation.

Extensive laboratory and field tests were conducted through the facilities of the Central Laboratory Testing Services of Albera Transportation. Assistance of many individuals in the Central Laboratory is greatly appreciated.

The cooperation of the contractors involved in the construction of the two 1982 Alberta recycling projects is thankfully acknowledged.

Finally, my special thanks to many individuals in the Department of Civil Engineering, University of Alberta, for their assistance and support.

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1. INTRODUCTION

1.1 General

Recycling is defined as the reuse, usually after some processing, of a material that has already served its first intended purpose.

Recycling of pavements is not new, but rising prices of asphalt binders have been a major stimulus in the development of new equipment and techniques, which has made recycling an exciting development in the field of asphalt paving. The recycling of asphalt pavements has increased dramatically during recent years. This has been due primarily to the favorable economics in constructing recycled pavements and the favorable publicity that is generated when natural resources are conserved.

The savings obtained by using this technology, in both energy and natural resources, have given impetus to many in-depth research projects. The ability to rejuvenate distressed pavements and reuse deteriorated pavement materials and perhaps, most importantly, the potential savings of petroleum binder cost are the most important factors in development of recycling technology.

Cost savings, energy savings, and the conservation of natural resources are not the only potential benefits from recycling. Other benefits may include:

1. Increasing the structural capability of the pavement without increasing its thickness,

2. Correcting existing mix deficiencies,
3. Correcting base problems,
4. Minimizing or eliminating reflective cracking problems,
5. Maintaining overhead structure clearances,
6. Correcting or eliminating surface deformation such as rutting or shoving.

Recycling of existing pavement can now be considered as an alternative to conventional rehabilition procedures for most projects.

As a technology, asphalt concrete pavement recycling has come of age (1).

1.2 Objectives of the Thesis

The primary objective of this research was to investigate the technology of asphalt concrete pavement recycling and to propose improved design and construction techniques.

The secondary objective was to assist in the development and implementation of a program for asphalt pavement recycling for Alberta Transportation. To meet this two 1982 central plant hot mix recycling projects were monitored and consequently design procedures and recommendations drawn for future recycling projects.

A further objective was to consider the potential cost savings and conservation of natural resources by the method of recycling used in these projects.

1.3 Scope of the Thesis

The processes associated with asphalt concrete recycling were examined and an extensive literature survey on past experience and current practice performed. Since only two recycling projects were constructed during the course of this research in Alberta, the test results utilized in this study are limited to these two projects.

This research is mainly confined to central plant hot mix recycling.

1.4 Organization of the Thesis

The introduction along with the objective, scope and organization of the thesis are given in Chapter 1.

In Chapter 2 various recycling categories utilizing different techniques and equipment are summarized.

Chapter 3 contains the factors that should be considered in selection of recycling projects.

Quality control procedures for recycled asphalt concrete are discussed in Chapter 4.

Chapter 5 presents a sequence of events necessary for the development of a mixture design for recycled asphalt concrete projects.

In Chapters 6 and 7 case studies which contain the design, construction and testing program of the two 1982 recycling projects in Alberta are discussed. The results of the tests performed and the observations obtained during the course of these two projects are analysed in these chapters.

A discussion on economic analysis of asphalt concrete recycling along with a calculation of the savings for the two Alberta recycling projects are given in Chapter 8.

Chapter 9 gives a summary of conclusions drawn from the literature review, case studies, and the results of tests and analyses. Recommendations for future recycling projects are contained in this Chapter.

2. RECYCLING CATEGORIES AND TECHNIQUES

2.1 General

The technology of pavement recycling has undergone significant advances, employing various methodologies depending on variations in pavement conditions and stages of pavement distress.

Recycling categories have evolved into the following schedule (2):

1. Surface recycling,
2. In place surface and base recycling,
3. Central plant recycling.

A brief description for each category is given below with more emphasis on central plant recycling.

2.2 Surface Recycling

Surface recycling is defined as reworking and/or removal of the surface of a pavement to a depth of approximately 25 mm by heater planer, heater scarifier, hot milling, cold milling or cold planing devices. The operation may involve the use of new materials including aggregates, modifiers and/or asphalt cement (3-8).

In the process of surface recycling heat may or may not be used for breaking up the surface, and the construction may be either continuous or multi-phased.

Surface recycling is only appropriate when the condition to be corrected is near the surface of the

existing pavement and there are not structural deficiencies. Some of the reasons for surface recycling are as follows:

1. To correct or eliminate surface deformation such as rutting or shoving,
2. To correct or eliminate a slippery surface,
3. In correcting the above, to maintain the original elevation of the surface, and
4. To minimize reflection cracking through an overlay.

A wide variety of recycling equipment has been developed and a number of innovative techniques for surface recycling are available. The equipment and the associated techniques have been categorized into heater planers, heater scarifiers, hot millers, cold planers, and cold millers.

2.2.1 Heater Planer

The heater planer is a device that heats the pavement surface and then shears up to 25 mm of the hot material with a steel blade or plate.

Heater planing has been used primarily for maintaining pavement longitudinal and transverse cross slope. Other uses include removing pavement from bridges to reduce the dead weight; maintaining proper clearances in tunnels, at underpasses; and removing surface irregularities from rough pavements(2).

2.2.2 Heater Scarifiers

The heater scarifier is a device that heats the pavement surface and rips the surface up to a depth of 25 mm by raking spring loaded steel points over the hot materials.

The basic recycling operations using heater scarifiers can be summarized as: preparing, heating, and scarifying the surface; adding additional material if required; compacting; making final adjustment to manholes and drainage structures; and opening the facility to traffic.

Heater scarifying can be used to remove pavement surface irregularities and roughness, to reduce reflection cracking, and to improve the bond between the old pavement and a new asphaltic concrete overlay.

2.2.3 Hot Miller

The hot miller is a device by which the pavement surface is heated and then milled with a rotating drum that has cutting tips mounted over the cylindrical surface. Hot milling has not been extensively used.

2.2.4 Cold Planer

The cold planer is a motor grader with hardened steel blades. The cold planing process is used to remove surface material that is deteriorated or causes surface roughness or slipperiness. The operation is normally considered to be maintenance, and the removed material is often reused.

2.2.5 Cold Miller

The cold miller is a device which uses a rotating drum with special teeth to cut a pavement to a predetermined depth. Its major application is the removal of surface deterioration. It is capable of removing pavement to a depth greater than 25 mm. Thus, this type of equipment can be used to provide pulverized material for in-place and central plant recycling operations as well as for surface recycling.

The types of pavement distress that can be treated by cold milling include rutting, ravelling, flushing, and corrugations of asphalt surface pavements (2).

Some uses of cold milling operations include:

1. Texturize the pavement surface to improve the skid resistance and provid a smoother riding surface,
2. Restore pavement geometry,
3. Repair localized failure areas,
4. Increase overhead clearance,
5. Extend life of the overlay because of providing a constant resurfacing thickness, hence uniform density.

2.3 In-Place Surface and Base Recycling

In-place surface and base recycling involves the reuse of existing surface, base, subbase and/or subgrade materials. In-place recycling techniques are different from the other broad categories of recycling in that all construction operations are performed in-place. New binders such as lime, portland cement and bituminous materials can

be used in the recycling process. After the roadway has been pulverized, mixed and placed, it will normally require a new wearing surface such as a surface treatment or asphalt concrete.

The types of equipment used for in-place recycling are very similar to that used for on-grade stabilization with lime, cement or asphalt. In general, the only specialized equipment is that used to properly size bound materials prior to restabilization. Specially designed pulverizers, hammer mills, or cold milling machines have been developed for this purpose (2).

Some of the advantages of in-place surface recycling operations include:

1. Ability to achieve significant pavement structural improvements,
2. All types and degrees of pavement distress can be treated,
3. Reflection cracking can be eliminated if the depth of pulverization and reprocessing is adequate,
4. Frost susceptibility of subgrade and subbase soils can be improved by use of the process,
5. The pavement ride quality can be improved,
6. Skid resistance can be improved, depending upon the type of surface placed on the cold recycled section,
7. Hauling costs are minimized.

2.4 Central Plant Recycling

Central plant recycling involves removal of the pavement from the roadway after or prior to pulverization; processing of material, either cold or hot at a central location, with or without the addition of a modifier; followed by laydown and compaction to the desired grade and depth.

Central plant hot mix recycling is emerging as the method with the great potential and the growth in its use is dramatic. Extensive research has been conducted in this field (9-13).

Equipment for hot recycling can be divided into three categories: 1) pavement removal and sizing, 2) reprocessing, and 3) laydown and compaction.

2.4.1 Pavement Removal and Sizing

Two approaches have been used to size the material prior to recycling in a central plant. The pavement can be reduced in size in-place and then hauled to the central plant, or the pavement can be removed from the site and crushed at the central plant.

In-place removal and sizing can be performed with equipment normally associated with surface and in-place recycling such as hot milling, cold milling and heater planing machines. The use of cold milling machines has been more widespread. This type of equipment is primarily used on projects which require only partial depth removal of an

existing pavement. The size of the milled product will vary depending on several factors: the cutting teeth, forward speed of the machine, depth of the cut, and properties of the reclaimed material. The milled material will usually be suitable for hot recycling without further size reduction, although there may be a small percentage of oversize that will need to be either crushed or screened off. There will usually be a slight increase in the aggregate fines as a result of milling.

Central plant sizing can be performed with conventional fixed and portable crushing and screening equipment. The pavement is normally ripped and broken up prior to loading in a size suitable to be received by the primary crusher. The asphalt concrete pavement may be removed full-depth by front-end loaders, bulldozers, or motorgraders. This type of removal technique is primarily used when an existing pavement exhibits distress which can only be corrected by complete reconstruction.

The reclaimed asphalt concrete pavement should be reduced to an appropriate maximum size through the crushing or milling processor. Based on past experience, this appropriate maximum size appears to be in the 35 to 50 mm range. Particles of this size seem to be able to break down into their original asphalt and aggregate components when put back through a batch or dryer-drum plant modified for recycling (12).

2.4.2 Reprocessing

The reclaimed material can be reprocessed along with additional new materials through a modified batch or drum mix plant to produce paving mixtures.

2.4.2.1 Batch Plants

In a conventional batch plant operation, virgin aggregate is dried and heated in a counterflow dryer, screened into various size fractions, proportioned with hot asphalt cement and thoroughly mixed. However, the only technique that has proven successful in recycling through a batch plant is the mixer heat-transfer method. In this method, virgin aggregate is superheated in the dryer and transferred to the tower by the hot elevator. The reclaimed asphaltic material, which has been previously reduced to an appropiate size and stockpiled at ambient temperature, is transferred to the weight hopper in the mixing tower by an auxiliary conveyor system. There it is proportioned with the superheated virgin aggregate. Heat transfer occurs as the two materials are mixed in the pug mill with additional asphalt cement and/or an asphalt softening agent (12).

The recycling of asphalt concrete through a batch plant by the heat-transfer method, is generally limited to very near 50 percent reclaimed material. Figure 2.1 shows a batch plant with reclaimed mix added to superheated aggregate at the pug mill.

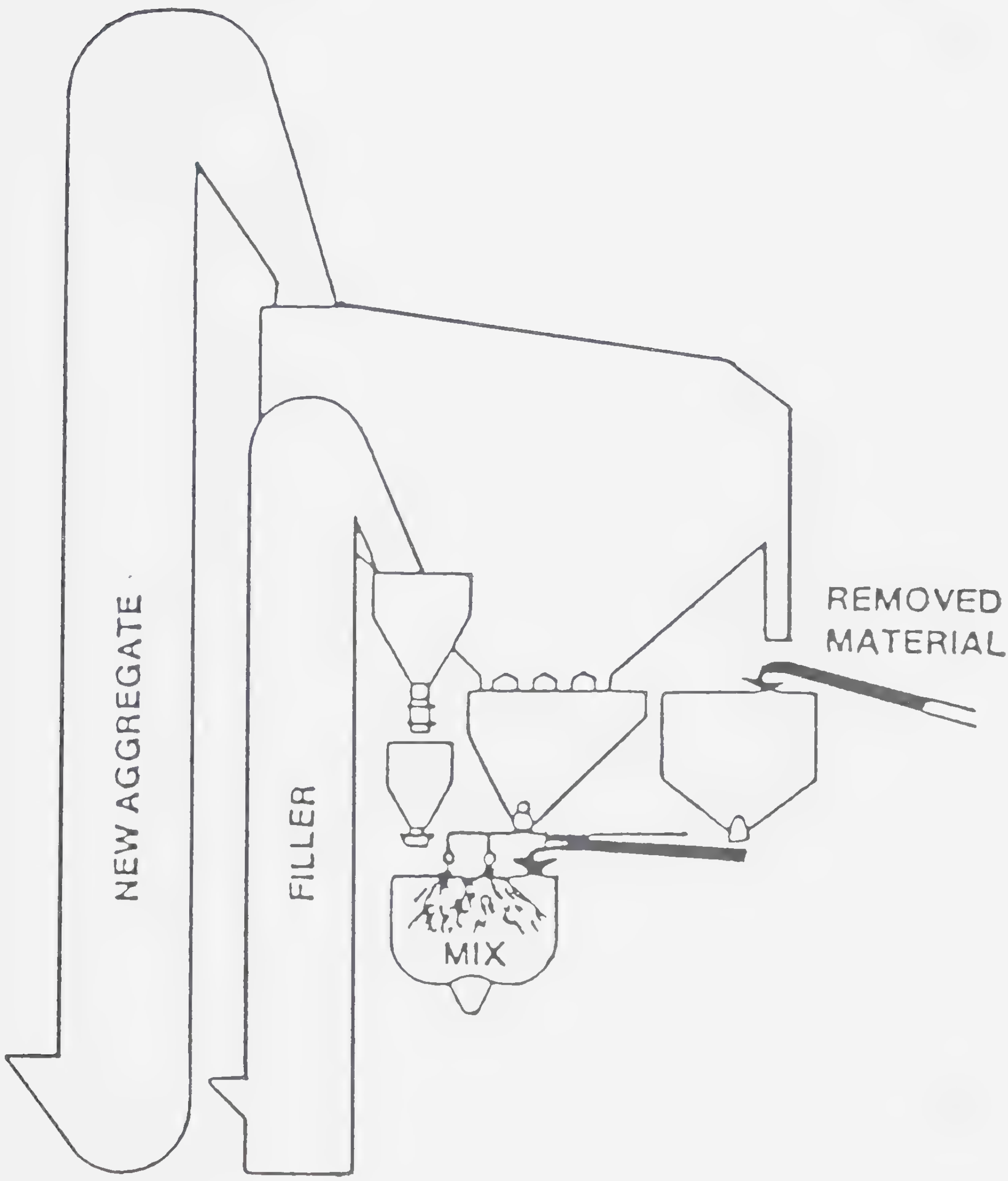


Figure 2.1 Standard Batch Plant with Reclaimed Mix Added to Superheated Aggregate at the Pug Mill

2.4.2.2 Drum Mix Plants

Drum Mix Plants differ from batch plants because the heating and drying of the aggregate, the asphalt addition and the mixing operation are all done inside the drum.

In a conventional drum mix operation, virgin aggregate is proportioned at the cold feed; then it is dried, heated, and mixed with hot asphalt cement in a parallel-flow dryer. Since the aggregate enters at the burner end of the drum, it is immediately exposed to very high temperatures from the flame and hot gases (12). However, in the case of recycling, exposing the reclaimed asphaltic material to high temperatures at the burner end of the drum may cause oxidation, vaporization and partial combustion of the existing asphalt together with production of very heavy smoke emissions. A considerable amount of effort has been made to develop modifications for drum mixers which would produce satisfactory mixes, maintain high production rates, and minimize air quality problems. The following sections briefly describe the plant modifications that have proven to be successful:

<u>Drum-Within-a-Drum-System.</u> With this system a conventional drum mix is modified by moving the burner back from the end of the main drum and inserting a smaller drum. The burner discharges into the upstream end of the smaller drum which extends coaxially into the

main drum (12). The virgin aggregate enters the inner drum within the main drum and is heated directly by the burner flame. Reclaimed material is introduced into the outer drum; it is heated both by the transmission of heat from the hot walls of the inside drum and, more particularly, by close contact with the heated virgin aggregates in blending together downstream. The two materials are then combined with additional new asphalt cement and/or softening agent and the mixing continues throughout the remainder of the main drum. This system can use a maximum of 50 to 70 percent reclaimed material. Figure 2.2 shows a Drum-Within-a-Drum System.

Split Feed System. In this system, the new aggregate is handled and processed in a normal manner,through the burner end of the drum mix plant. The reclaimed material, however, is fed into the plant through a separate cold feed system, with the point of entry of the material just beyond the mid-point of the length of the drum. The new aggregate, introduced into the radiation zone of the drum mix plant, is heated and dried. Figure 2.3 shows a Split Feed System. Depending on the relative proportions of new and reclaimed aggregate used in the recycled mixture, the new aggregate is superheated to a temperature between 150°C and 315°C by the time it reaches the mid-point of the drum. The combustion gases from the burner are cooled by the new aggregate to a 450°-530°C range by the time the

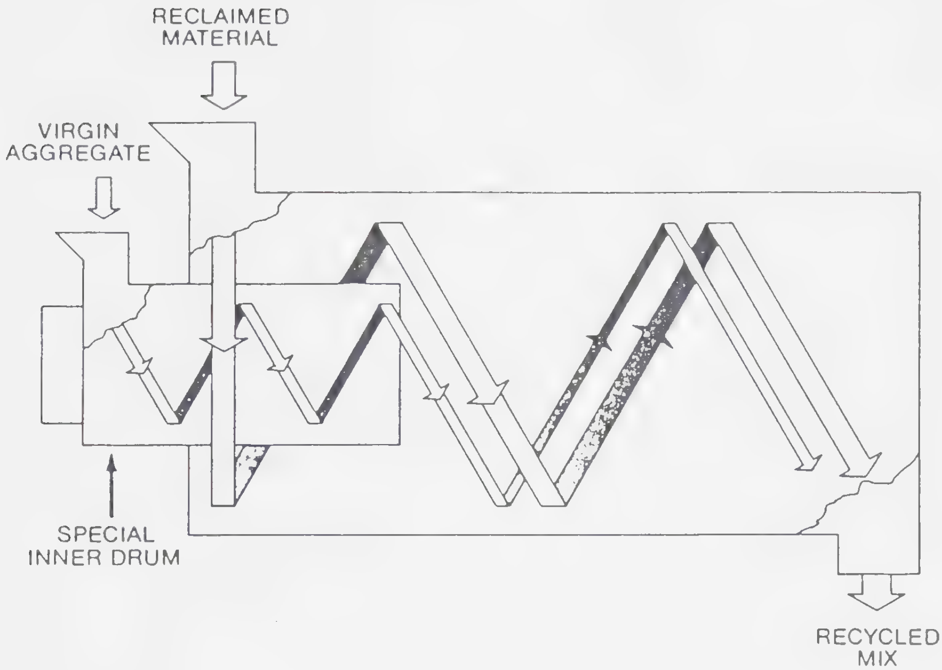


Figure 2.2 Drum-Within-A-Drum System

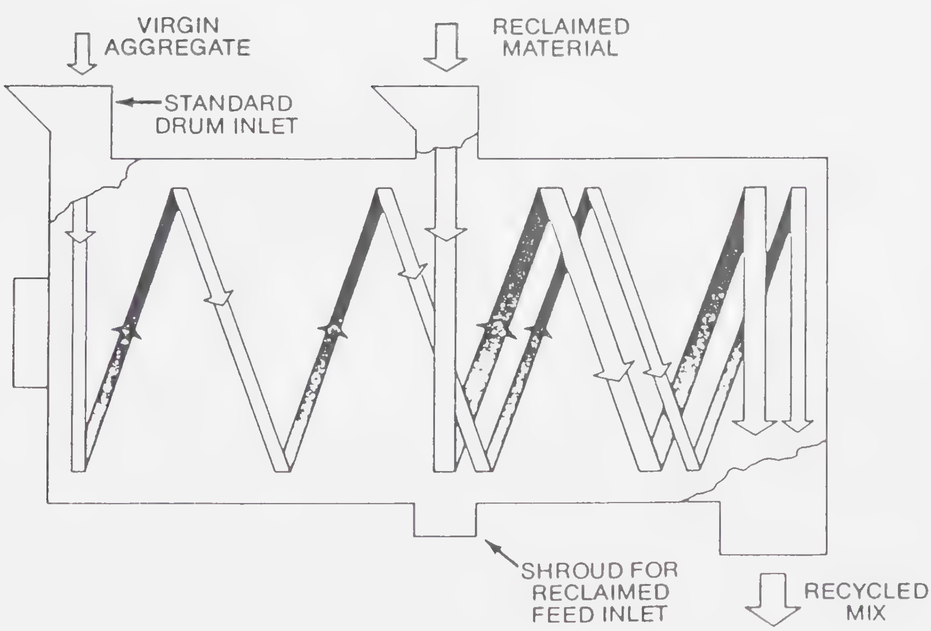


Figure 2.3 Split Feed System

gases reach the drum mid-point. A charging conveyor, completed with a weigh bridge system, feeds the reclaimed material into a rotary inlet and deposits it in the bottom of the drum, in a short area where no flights are located. Heat transfer begins to take place between the new aggregate and the reclaimed material. The new asphalt cement and/or softening agent is pumped into the drum and mixed with the combined aggregate at this point in the process. Heat transfer between the new and reclaimed aggregate continues by convection and conduction, as the blended material moves down the drum to the discharge end (14). This type of system can use a maximum of approximately 60 to 70 percent reclaimed asphaltic material.

Pyrocone System. This system controls the heat transfer rate at the burner end of the drum to prevent overheating the reclaimed asphaltic material. Heat rates are controlled by containing the complete combustion process and flame volume within the Pyrocone's cylindrical chamber where secondary air enters through slots in the chamber wall and mixes with combustion gases to produce a lower temperature air-rich mixture. Figures 2.4 and 2.5 show the Pyrocone and the Pyrocone System. The reclaimed asphaltic material and the virgin aggregate enter the drum by a single conveyor at the burner end. The material is gradually heated and blended, additional asphalt cement and/or softening

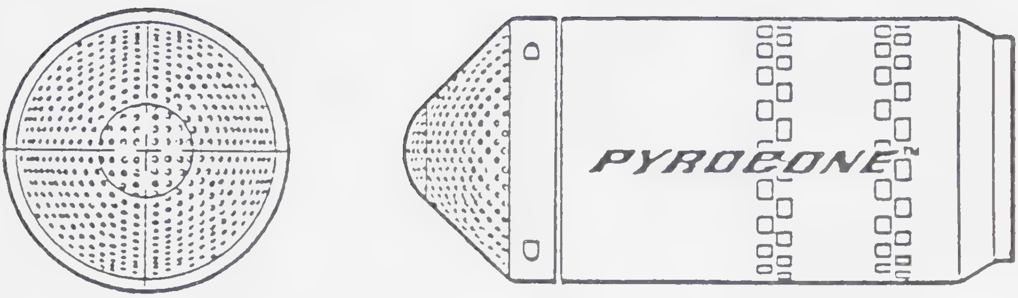


Figure 2.4 Pyrocone

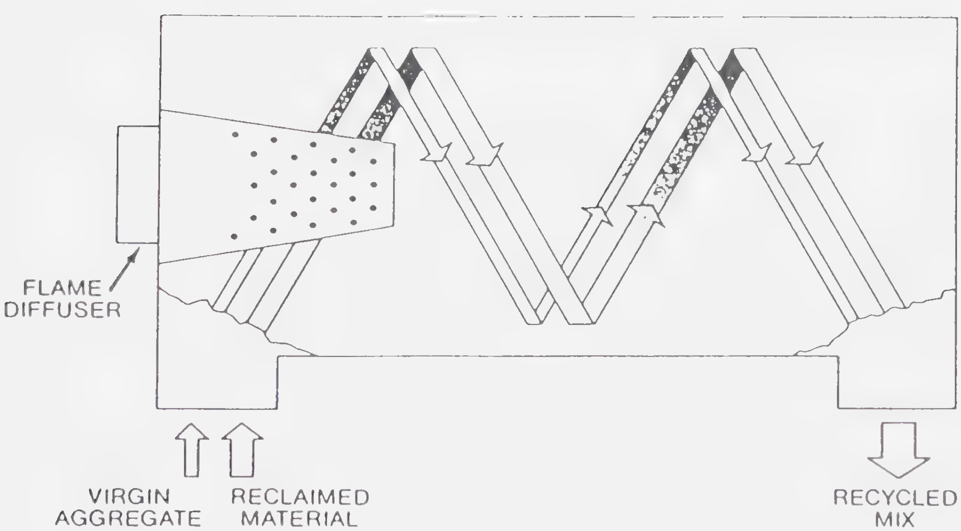
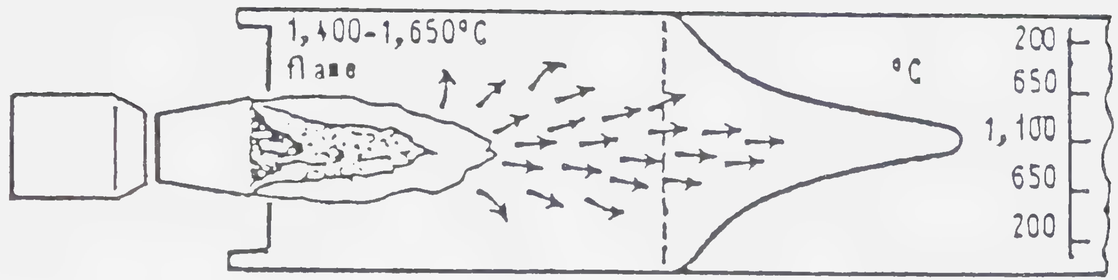


Figure 2.5 Pyrocone System

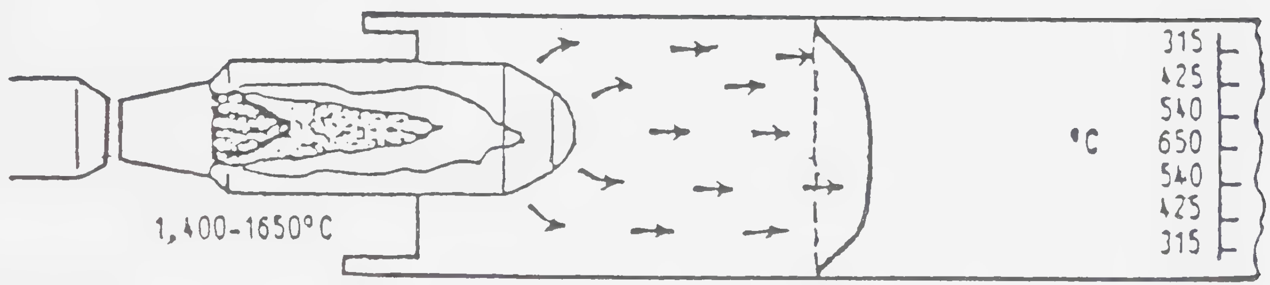
agents are added, and mixing is completed in the remainder of the drum.

The reduced heating rates produced by this system are the result of the following interrelated factors (12):

1. The heat shield ("pyrocone") reduces direct heat radiation by blocking a major portion of the line-of-sight path between the burner flame and the material to be heated.
2. The turbulent air mixing action in the pyrocone develops a uniform gas temperature distribution over the drum cross section. The uniform gas temperature will transfer heat to the cold material slower and more evenly than an intense narrow-band temperature distribution.
3. By mixing cool outside air with the hot combustion gases, the pyrocone lowers the temperature of gases in the front end of the drum from 1650°C to a range of 425° to 815°C. This also substantially lowers the heat transfer rate between the incoming gases and the cold, asphalt-coated aggregate. Figure 2.6 shows the temperature profile. This system does have the capability of using 100 percent reclaimed asphaltic material, but a more reasonable maximum to expect in order to control smoke emissions is approximately 60 to 70 percent. The pyrocone can be readily removed, if conventional mix is to be produced (12).



Standard Drum Mixer



Drum Mixer with Pyrocone

Figure 2.6 Temperature Profile

2.4.3 Laydown and Compaction

Laydown and compaction of recycled mix can be accomplished using the same equipment and procedures used for conventional mix. Normally the mixes containing the reclaimed materials are handled in the same manner as conventional mixes, provided the laydown temperatures and viscosities have been comparable.

3. PROJECT SELECTION FOR RECYCLING

3.1 General

The success of any pavement design and construction process is first one of selection. The key factors that influence the decision in project selection for recycling include:

1. Existing Facility,
2. Pavement Condition,
3. Cost and Energy Comparison,
4. Environmental Consideration.

These factors are discussed in the following sections.

3.2 Existing Facility

The existing facility can be described by a set of particular data for the purpose of rehabilitation decision making (2). These data are summarized as follows: 1) Location and size of project, 2) roadway class, 3) existing pavement cross section, 4) Geometrics, and 5) traffic characteristics. Each factor is briefly described below.

Location and Size of Project. The location and size of the project may be such that only certain techniques would be cost effective. For example, projects located in remote areas will have to be large in size to justify the transportation of the equipment associated with central plant recycling. In place recycling is a cost effective approach for pavement rehabilitation in remote areas where

small projects with low traffic volumes are under consideration (2).

Roadway Class. Generally the roadway class dictates criteria for determining the need for pavement rehabilitation as well as general criteria for selection of an appropriate recycling alternative (2).

Existing Pavement Cross Section. The data of original construction together with a listing of the thickness and types of materials used will be important in judging the general serviceability of the pavement. Subsequent history of rehabilitation and maintenance activities will influence the determination of a viable recycling alternative (2).

Geometrics. The geometric features of a roadway such as horizontal and vertical alignment, are often constraints to conventional rehabilitation techniques such as asphalt overlays. Recycling of existing pavement materials offers a solution to some of these problems (2).

Traffic Characteristics. Speed and volume of traffic, to a large extent, determines the traffic control problems associated with pavement rehabilitation activities (2).

3.3 Pavement Condition

One of the first decisions necessary in selecting a project for possible recycling is the condition of the pavement. The need for resurfacing, restoration and rehabilitation or reconstruction, is usually brought about by one or more of the following pavement deficiencies (3):

1. Pavement roughness,
2. Excessive cracking,
3. Excessive rutting in the wheel paths,
4. Low skid number,
5. Surface wear or ravelling,
6. Inadequate pavement structure.

A brief description of these pavement deficiencies and their influence on selecting a recycling alternative is given below.

Pavement Roughness. The smoothness of ride may be a deciding factor for rehabilitation of many roadways. Pavement roughness in most cases can be corrected by surface profiling, by cold milling, or heater planing, combined with resurfacing.

Excessive Cracking. Excessive cracking can be corrected by several of the available recycling procedures. A systematic procedure for identification of the extent and severity of cracking should be organized. Surface recycling can be appropriate for minor cracking, however in the case of extensive and severe cracking, in-place or central plant recycling should be considered.

Excessive Rutting. This kind of pavement distress can generally be corrected by surface planing or milling in combination with a surface treatment or thin overlay. The thin overlay could be produced either from virgin mixes or a combination of reclaimed and virgin material. In some cases, surface recycling may not be sufficient to correct problems

in the base or subbase, in which case in-place or central plant recycling may be the proper option.

Low Skid Number. Many pavements may perform adequately from a structural standpoint but simply be deficient in skid resistance because of excess asphalt cement or perhaps because of polishing aggregate (2). Deficiency in skid resistance can be corrected by surface planing or recycling with a minimum of new materials. In extreme cases central plant recycling with some percentage of virgin non-polishing aggregate may be required.

Ravelling. Severe ravelling can be corrected with surface recycling with or without the addition of new materials.

Inadequate Pavement Structure. This can be corrected by increasing the depth of stabilization by means of in-place or central plant recycling. If necessary, a new wearing surface can be added as a precaution against accelerated surface wear.

In summary, a range of alternative recycling procedures can be used to correct any deficiency that can be corrected by the use of new materials.

3.4 Cost and Energy Comparison

Cost is the traditional criteria for selection between various design and rehabilitation alternatives. Another consideration which may or may not be reflected by comparative cost is energy. The cost and energy factors

involved in various recycling techniques should be compared with those involved in conventional procedures. Various recycling techniques can be used to save energy and reduce costs in rehabilitating pavements. For highway reconstruction and rehabilitation procedures, the more important energy considerations are the amounts of transport and construction energies used. These are likely to have the more significant effect on costs. A number of recycling techniques offer means for conserving significant amount of energy and reducing costs over traditional ways of rehabilitation. The amount of energy saved and reduction in costs will depend on the conditions of each project.

3.5 Environmental Consideration

There are environmental considerations concerning the use of recycling procedures. They are specifically related to safety, noise and air pollution. Of these three, the only one that appears to be significant is air pollution and particularly opacity requirements. The current solution is to spray water on the cold feed materials, to increase the amount of virgin material or decrease plant production (3). Some modification in equipment could help to reduce the air pollution problem, however, the general solution is to reduce the amount of reclaimed material used in the mix.

4. QUALITY ASSURANCE OF RECYCLED ASPHALT CONCRETE

4.1 General

The quality of a recycled mixture depends on the salvageable materials available and how these and new materials combined and processed to produce a recycled mixture. The handling and processing technique play an important part in controlling the level of quality in the final product. Proper specification control is required in order to produce high quality paving mixtures.

There are a series of steps which must be conducted to insure a satisfactory recycled asphalt concrete pavement. These steps include: assessment of the existing pavement, evaluation of the reclaimed asphalt concrete, preliminary design, final design and construction control.

4.2 Assessment of the Existing Pavement

An important part in the assessment of the existing pavement is to conduct a detailed condition survey, to determine the type of distress that has occurred and, also its severity, its extent, and the location. A number of factors must be considered in Planning Procedures for the existing pavement condition surveys, such as: 1) determination of homogeneous sections which refers to the selection of sections that are essentially alike, 2) type, density and severity of distress which involves visual observations of the physical condition of the roadway.

Generally the types of distress which may be encountered are(15):

1. Surface defects: including ravelling, aggregate loss and flushing.
2. Permanent deformation: including rutting, shoving and corrugations.
3. Cracking: including longitudinal cracking, transverse cracking, alligator cracking and others.

Usually these types of distress are broadly associated with environment, traffic or materials.

Identification of the nature and cause of distress which led to the need for rehabilitation is essential in designing any recycling project.

It is important to identify whether distress is caused by either the mixture problems or structural inadequacy or both. Accordingly, specific considerations should be given in the design stage.

4.3 Evaluation of Reclaimed Asphalt Concrete

For the material obtained from the existing pavement, variations in layer thickness and type of asphalt concrete mixtures, according to data from prior sampling and original construction plans, must be established (16). From the results of the pavement condition surveys, performed previously, variations in the type, extent, and severity of pavement distress may provide indications where additional samples should be taken for evaluation of the existing

asphalt concrete pavement.

For characterization of the existing pavement, a series of tests should be performed on the representative samples in order to determine the asphalt content, aggregate gradation and to recover asphalt cement for further testing. Analysis of the existing materials consists of extracting the asphalt binder from the mixture and recovering this asphalt from asphalt-solvent solution. After the asphalt and aggregate are recovered, they are subjected to a detailed testing program.

Extraction of reclaimed materials requires considerably more time to complete than does a conventional mix extraction. The present methods of extraction are the major impediment in good quality control of reclaimed asphalt concrete.

Any experience with any of the popular extraction techniques will show that none of them are very fast and all are of questionable accuracy and reproducability, especially when using different operators and test methods (17). However, it is essential to perform extraction and evaluate the properties of the existing reclaimed materials, to determine aggregate and asphalt type that must be used to modify these materials to meet the specification requirements.

4.4 Preliminary Design

The main objective of the preliminary design is to arrive at the proper selection of the virgin aggregate, virgin asphalt cement, and asphalt rejuvenator.

As an asphalt concrete pavement ages in service, significant changes may take place in the properties of the constituent materials. Asphalt cement hardens and loses ductility which subsequently makes the pavement susceptible to cracking and ravelling. The aggregate also changes. Aggregate particles degrade under heavy traffic. Reclaiming operations also contribute to aggregate degradation.

Depending upon the type of failure of the existing pavement, different approaches may be chosen to restore the materials to their original properties.

If a brittle failure, for example cracking, has occurred, the design involves the selection of a recycling agent which will soften the existing asphalt and return it to the original characteristics (18). However, if a nonbrittle failure, for example excessive rutting, has occurred, a harder asphalt grade may be selected in order to upgrade the old asphalt cement and to eliminate the existing problems.

Therefore, it is essential at this stage of design to select the proper type and amount of additives which can be used to recondition the asphalt cement and upgrade the aggregate to meet the specifications.

4.5 Final Design

The primary objective of the final design is to produce a high quality asphalt concrete mixture with acceptable stability, durability, and strength characteristics.

In the final design, the mixture properties of the materials selected for the preliminary design are evaluated and an optimum mix design is selected for the project. This design, however, is vulnerable to change as the construction proceeds.

A detailed procedure and discussion for this stage of design is given in the next chapter.

4.6 Construction Quality Control

The quality control and testing during construction for recycled asphalt concrete is very similar to that of conventional mixtures. However, some additional testing is required during the construction.

A major addition to the standard testing procedures is the control of the consistency of the asphalt cement in the final recycled asphalt concrete mixture. This includes recovery of the extracted asphalt and a measurement of the penetration and viscosity of the recovered asphalt. Recovery of the asphalt cement should be made at regular intervals during the production process to insure that the recycled asphalt concrete mixture is acceptable.

Grading analysis of the reclaimed aggregate should be monitored daily along with the amount of extracted asphalt

from the reclaimed materials.

Corrective actions should be taken immediately, if the variation of the test results exceed the tolerance limits given in the final design.

With the exception of additional tests, the recycled asphalt concrete mixture should be produced and placed using the same techniques as that for conventional mixtures.

Standard compaction requirements for conventional asphalt concrete paving must also be applied to the recycled mixtures, and no deviation from standard specifications should be allowed.

More detailed discussion on the construction quality control and testing procedures is given in Chapters 6 and 7.

5. RECYCLED ASPHALT CONCRETE MIXTURE DESIGN

5.1 General

The purpose of this chapter is to address necessary procedures required to produce an acceptable recycled asphalt concrete mixture.

Procedures for the design of recycled pavements have not yet been standardized, however several agencies have published guides for the recycled mixture design (19-27). Alberta Transportation recycled pavement mixture design is presented in Chapters 6 and 7 for the two 1982 projects.

In general the purpose of mixture design is to utilize the reclaimed pavements, new aggregate and modifier to produce quality recycled asphalt mixtures. Greater care may be required in recycled mixture design, since the basic materials used are reclaimed from a failed pavement and hence modification of these reclaimed materials is required.

The procedures presented here for the development of a mix design for recycled asphalt concrete projects are what the author believes to be a preferred sequence of events.

5.2 Recycling Modifier

The reclaimed asphalt often has characteristics which are undesirable for reuse without any modification. A recycling modifier may be used to restore the reclaimed asphalt to the required specifications. The recycling modifier must be able to modify the properties of the

asphalt binder to the desired characteristics.

Generally the purpose of a modifier in asphalt paving recycling is to (19):

1. Restore the recycled or old asphalt characteristics to a consistency level appropriate for construction purposes and for the end use of the mixture,
2. Restore the recycled asphalt to its optimum chemical characteristics for durability,
3. Provide sufficient additional binder to coat any new aggregate that is added to the recycled mixture and,
4. Provide sufficient additional binder to satisfy mixture design requirements.

The type, source and consistency of the reclaimed asphalt has a profound effect on the selection of the recycling modifier.

Recycling modifiers can contain different categories such as softening agents, rejuvenators, flux oils and soft asphalt cements.

5.3 New Aggregate

Depending upon the recycling ratio chosen, the percentage of the new aggregate in the recycled mixture can be specified.

New aggregate may have to be added to the mixture for one or more of the following purposes (19):

1. Satisfy gradation requirements,
2. Skid resistance requirements for surface courses,

3. Air quality problems associated with hot central plant recycling,
4. Thickness requirements,
5. Improved stability, durability, flexibility, etc., and
6. To allow the addition of sufficient modifier to restore the aged asphalt to specification requirements.

In order to fulfill the above purposes and, in particular to meet the air quality regulations, use of a minimum percent of new aggregate is necessary. This minimum value may change with the use of different kinds of asphalt plants. Generally the specified minimum is larger for batch plants when compared to drum mixers. This requirement may gradually decrease as a result of improvement in equipment and recycling operation.

Depending upon the gradation of the reclaimed aggregate, the new aggregate gradation can be specified. The blend of the new and reclaimed aggregate should meet the specification requirements for gradation of total aggregate.

5.4 Mix Design Laboratory Procedures

The steps necessary for the design of recycled asphalt mixtures are outlined as follows:

1. Evaluation of the reclaimed material,
2. Determination of the amount and gradation of the new aggregate,
3. Selection of the type and grade of the recycling modifier,

4. Proportioning and testing trial mixes and
5. Establishing the job mix formula.

The above procedures should be carried out carefully in order to obtain quality recycled asphalt concrete mixture. Description of each step is presented below.

5.4.1 Evaluation of the Reclaimed Material

Extraction and recovery of the asphalt and aggregate from the reclaimed pavement and determination of their amounts should be first carried out in order to evaluate the reclaimed pavement.

Reflux method (ASTM D 2172-81,B) is used for quantitative extraction of asphalt. The extracted asphalt is recovered from solution by the Abson method (ASTM D 1856). To measure the consistency of the recovered asphalt the following tests should be conducted:

1. Penetration at 25°C (ASTM D 5),
2. Absolute viscosity at 60°C (ASTM D 2171), and
3. Kinematic viscosity at 135°C (ASTM D 2170).

Asphalt content, penetration and viscosity should be determined on all samples, since it gives a measure of project uniformity. Sufficient asphalt should be recovered in order to be blended with recycling modifier for further testing.

The recovered aggregate from the reclaimed pavement should be tested for gradation. The gradation is determined according to ASTM C-136. It may also be desirable to check

aggregate soundness (ASTM C-88), number of crushed faces, and aggregate toughness (Los Angeles Abrasion Test, ASTM C-131).

5.4.2 Amount and Gradation of the New Aggregate

The percentage of the new aggregate in the recycled mixture is governed by the choice of the recycling ratio. However, evaluation of the reclaimed material described in the previous section should be used as a feedback for selection of the mentioned recycling ratio.

The new aggregate should be combined with the reclaimed aggregate to obtain a final gradation that will comply with standard gradation requirements. Any deficiency in the gradation of the reclaimed aggregate can be adjusted with the addition of new aggregate of the proper size and gradation. Also, any stability deficiency in the reclaimed pavement material can be corrected with the addition of proper new aggregate.

5.4.3 Selection of Type and Grade of Recycling Modifier

The grade of the recycling modifier and the target consistency of the asphalt in the recycled mixture is selected at this stage of the mix design.

The recovered asphalt is blended with selected types of recycling modifier at various ratios. These blends are tested for:

1. Penetration at 25°C,

2. Viscosity at 60°C, and
3. Penetration at 25°C and viscosity at 60°C on the residue after the Thin Film Oven Test.

The relationship between penetration or viscosity of the treated asphalt and the percentage of the recycling modifier are plotted on arithmetic scales for selected typed of modifiers. Typical plots are shown in Figures 7.2 and 7.3 of Chapter 7. The type of modifier to give the desired consistency in the recycled asphalt cement is then determined.

5.4.4 Proportioning and Testing Trial Mixes

Specimens of mixtures containing reclaimed pavement, new aggregate and recycling modifier should be prepared. Trial mix designs following the Marshall method are performed for various percentage of binder contents. Specimens are subjected to stability testing and air voids determination. Extraction and recovery tests should be carried out on the selected test specimens. The properties of the extracted and recovered binder from the laboratory prepared and recycled mixtures are an indication of the compatability and durability of the recycling modifier.

The resilient modulus appears to be the best single test to identify the effect of the modifier on the mixture. This test is sensitive to the properties of the binder and will help to define the amount of modifier required to produce a binder of known consistency (19).

Selection of the optimum mix design should be based on stability requirements and air voids criteria. Resilient modulus also should be considered. The optimum mix design establishes the percentage of each of the various materials to be used in the mixture to insure that the combined aggregate properties, asphalt properties, and mixture properties are satisfactory.

5.4.5 Establishing the Job Mix Formula

An optimum mixture design meeting the specified requirements, as a result of the previous step, is selected.

A job mix formula is then prepared giving the design weight percent of the reclaimed material, new aggregate and recycling modifier. New and combined aggregate gradation, design binder content and mixture properties are then recommended.

Laboratory mixture design is the starting point for the field mixture and is subjected to change according to field conditions and workability requirements. The field mix design may be no more than a verification of the laboratory mix design, but it is necessary to determine that the mixture produced at the plant is satisfactory prior to full scale production.

The recycled mixture should be carefully designed to ensure that laboratory heating, mixing and compaction conditions correspond as closely as possible to the field.

6. CONSTRUCTION OF RECYCLING PROJECT NO. 1

6.1 General

This project on Highway 2:26 and 2:28, from west of Lacombe to west of Millet, was the first contract awarded for hot mix asphalt concrete recycling on the Provincial highway system in Alberta and was designed and constructed during the summer and fall of 1982 (28-30).

The recycling section was on the outer northbound lane of Highway 2 from km 42.000 to km 45.223 of control section 2:26 and from km 0.000 to km 14.970 of control section 2:28. The total length of recycling was 18.193 lane-kilometers.

This highway carries heavy commercial traffic, and also recreational traffic throughout the year. In 1981, this section of the highway was determined to be carrying an Average Annual Daily Traffic (AADT) of 11 000 with 20 percent trucks.

Lahrman Construction Ltd. of Calgary was the prime contractor for the recycled asphalt concrete paving operation. Major equipment used was a 400 tonne/hour Boeing Drum Mix Plant equipped with a Pyrocone, a Barber Greene SB-131 Paver, two Dynapac dual drum vibratory rollers and a pneumatic tire roller.

Budd Bros. Ltd. of Calgary was the subcontractor who performed the cold milling operation. They employed a PR-575 Roto Mill with a 1.83 m (6 ft) mandrel, and PR-450 Roto Mill with a 2.74 m (9 ft) mandrel. Both of these cold milling

machines were manufactured by CMI Corporation.

6.2 The Existing Pavement

Highway 2 is a four-lane divided highway. The cross-section generally consisted of 7.32 m wide Asphalt Concrete Pavement (ACP) with 2.95 m of outside and 1.63 m inside ACP shoulder, shown in Figure 6.1. Cold milling and recycling is confined to the outer northbound lane. This section of highway was constructed in the period of 1964-1966 and has the following existing pavement structure:

100 mm of 16 000 μm topsize ACP (1965-1966)

50 mm of 20 000 μm topsize asphalt stabilized base course (1964-1965)

50 mm of 20 000 μm topsize granular base course (1964-1965)

250 mm of 40 000 μm topsize granular base course (1964-1965)

The original asphalt cement used was of a 200-300 penetration grade and could be described as a low viscosity or highly temperature susceptible asphalt. Table 6.1 shows the aggregate source, asphalt supplier and asphalt grade for this section of highway. Tables 6.2 and 6.3 show the mix design done in 1965-1966 for Ponoka #2 and #3 pit sources.

The sieve sizes shown are the metric equivalents to the U.S. standard size designations used previously. The Marshall Test values have been converted to SI units to conform with current practice.

TABLE 6.1

Aggregate Source, Asphalt Grade and Asphalt Supplier
Project 2:26, 2:28

Section km to km		Aggregate Source	Asphalt Supplier	Asphalt Grade
2:26	km 42.000 to km 45.223	Ponoka #2	Imperial Edmonton	200 - 300
2:28	km 00.000 to km 2.410	Ponoka #2	Imperial Edmonton	200 - 300
2:28	km 2.410 to km 14.720	Ponoka #3	Imperial Edmonton	200 - 300
2:28	km 14.720 km 14.920	Ponoka #3	Husky Lloydminster	200 - 300

TABLE 6.2

Mix Design and Aggregate Gradation for Ponoka #2 Pit (1965)

Project 2:26, 2:28

Gradation				
Sieve Size µm	Av. % Passing			
16,000	100	Asphalt Content	%	6.2
5,000	51	Density	kg/m^3	2278
1,250	39	Stability	N	4960
315	15	Air voids	%	4.0
80	5.8	V. M. A.	%	15.4
		Void filled with asphalt	%	74.0
		Flow	mm	2.4

TABLE 6.3

Mix Design and Aggregate Gradation for Ponoka #3 Pit (1966)

Project 2:26, 2:28

Gradation				
Sieve Size µm	Av. % Passing			
		Asphalt Content	%	5.4
		Density	kg/m^3	2314
20,000	100	Stability	N	5916
5,000	50	Air Voids	%	3.9
1,250	34	V. M. A.	%	14.1
315	14	Voids filled with asphalt	%	72.5
80	6.3	Flow	mm	2.1

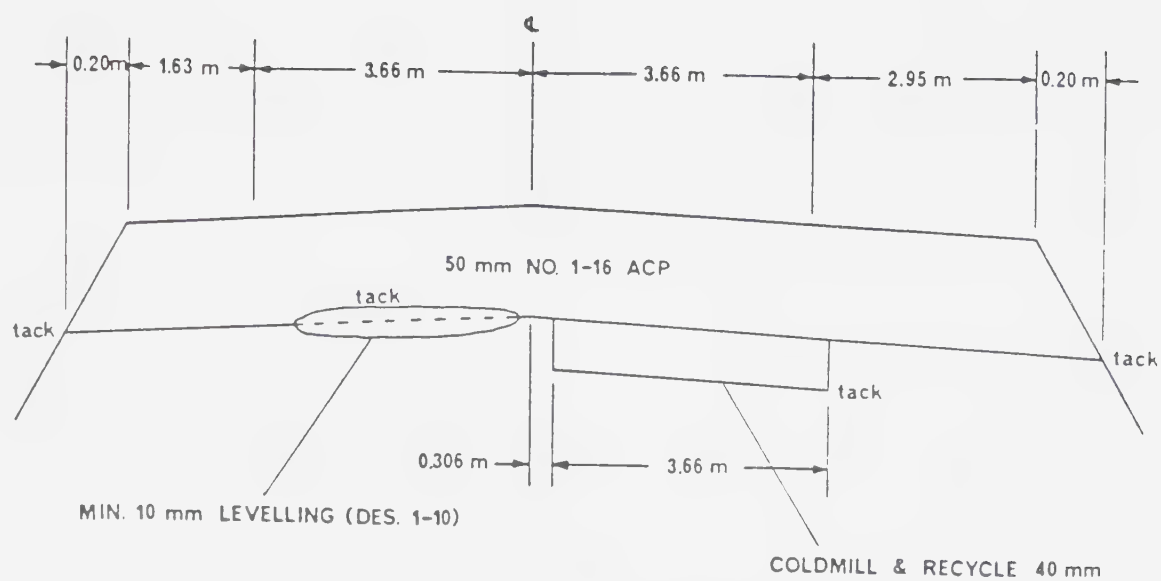


Figure 6.1 Typical cross-section, Project 2:26 & 28

Detailed information on the design and construction of the section 2:28 using Ponoka #3 aggregate has been reported as part of an earlier extensive study directed towards determining the variability of the asphalts as used and their subsequent behaviour in service (31).

The termination of the low viscosity asphalt supplier was at km 14.72 with the end of the recycling section at km 14.920. Field condition surveys showed that severe rutting was confined within the limits selected for cold milling.

The condition of the existing pavement may be summarized as follows:

Benkelman Beam spring rebound ($\bar{x} + 2\sigma$): 1.12 mm (0.044 in) (1981).

RCI : 5.5 - 6.0 (1981).

Surface condition: major bleeding, severe transverse low temperature cracking averaging 7.3 m spacing and severe rutting in the outside lane averaging 20-25 mm and up to 45 mm.

The rut depths were measured with 1.8 m (6 ft) straight edge. Cores taken across the outer lane at three stations indicated that rutting was due primarily to a reduction in thickness of the ACP surface course and asphalt stabilized base course.

6.3 New Pavement Design

The existing pavement on the outside travelled lane was to be cold-milled to a depth of 40 mm and a width of 3.66 m and be replaced with recycled mix. The reason for that was severe rutting distortion in the outside lane. The cold-milled area was to be shifted approximately 0.3 m off center line to the outside shoulder, in order to remove the pushed-up pavement existed along the painted shoulder line.

The inside travelled lane required only minor levelling. The entire roadway width was then to be overlaid with one 50 mm lift of virgin mix. Reference may again be made to Figure 6.1.

6.4 Project Mix Design Procedure

Mix design procedure followed these steps as shown in Figure 6.2.

1. The first step was to evaluate the properties of the Reclaimed Asphalt Pavement (RAP), thus 10 pairs of 150 mm diameter cores were sampled within the job limits.
2. Using one core from each pair, the following tests were performed:
   - quantitative extraction of asphalt by reflux method (ASTM D 2172-81, Method B),
   - recovery of asphalt by the Abson method (ASTM D 1856-79),
   - penetration at 25°C and viscosity at 60°C

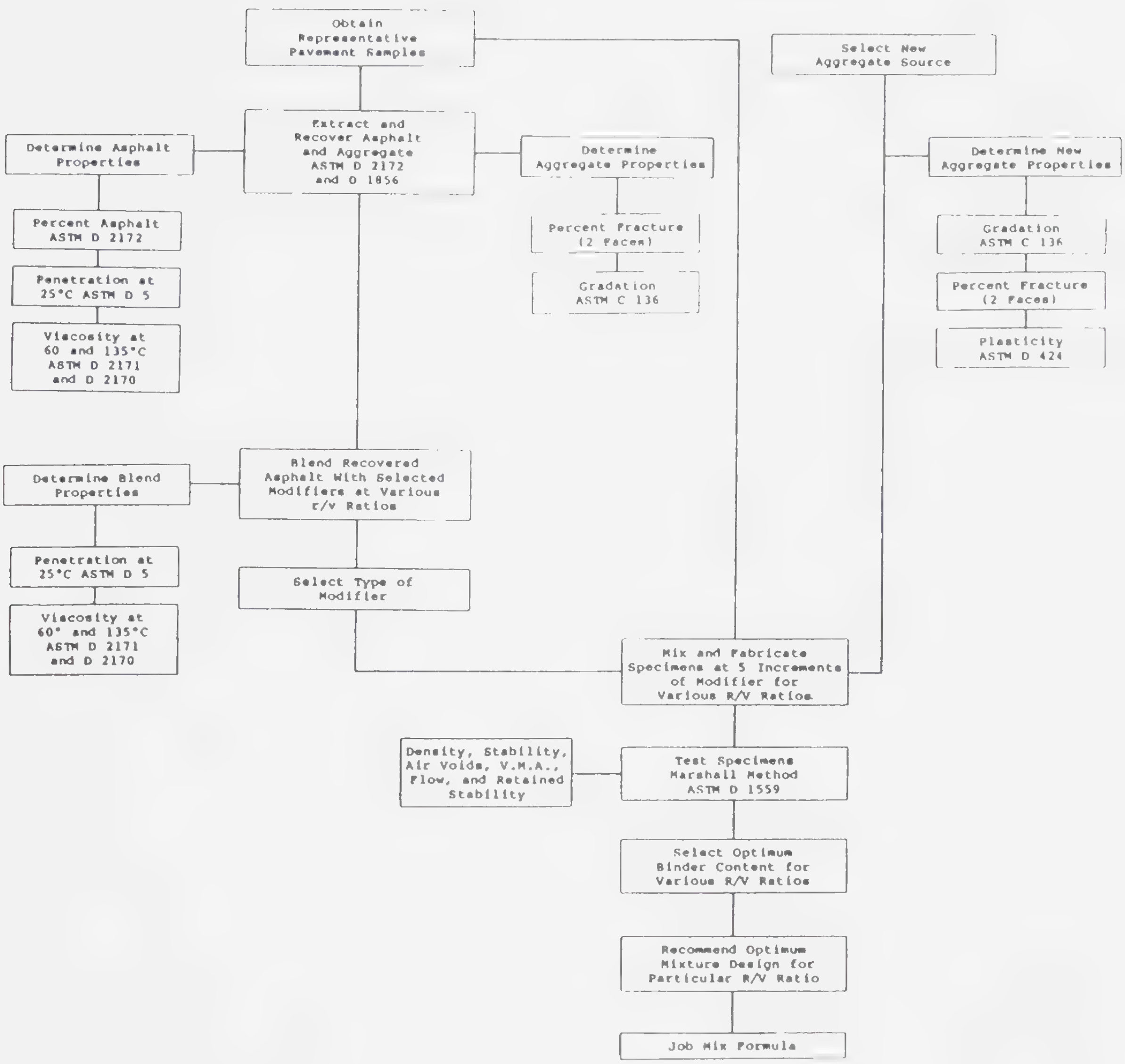


Figure 6.2 Mixture Design Procedure, Project 2:26,2:28

and 135°C of the recovered asphalt, and

-aggregate gradation.

The test results are shown in Table 6.4. It should be noted that the recovered asphalt has a penetration at 25°C of 176 dmm and absolute viscosity at 60°C of 31 Pa.s. It was considered that a softening agent was not needed and a harder grade of virgin asphalt cement was required in order to achieve a binder more resistant to rutting than the original.

3. The recovered asphalt was batched together and blended at various "reclaimed asphalt to virgin asphalt ratios" (r/v) with two different virgin asphalt grades: one similar to the original asphalt grade, 200-300 A, and the other one grade "harder", that is, 150-200 A. These blends were tested for:

   - penetration at 25°C,
   - viscosity at 60°C, and
   - penetration at 25°C and viscosity at 60°C on the residue after the Thin Film Oven Test.

   The penetration and viscosities for various r/v ratios were plotted on arithmetic scales and the relationships were approximately linear. Therefore, if the characteristics of some other virgin asphalt were assumed, estimates of the penetrations and viscosities of the blends at various ratios could be made without carrying out physical testing. Figure 6.3 shows the relationship between viscosity at 60°C and r/v ratios

TABLE 6.4

Aggregate Gradation and Asphalt Properties From Core Analysis

Project 2:26, 2:28

Gradation			
Sieve Size µm	Av. Percent Passing		
16 000	99	Recovered A.C. %	6.0
10 000	74	Pen. @ 25°C dmm	176
5 000	53		
1 250	32	Abs. Viscosity @ 60°C pa.s	31
630	23		
315	15	Kinematic Viscosity @ 135°C mm^2/s	187
160	10.4		
80	8.1		

for various asphalt grades. Figure 6.4 shows the characteristics of various blends using reclaimed asphalt from the project and four different virgin asphalt grades. It should be noted that the values shown using virgin grades 100-120 A and 120-150 A are only estimates.

4. Trial mix designs following the Marshall method were carried out at various "reclaimed to virgin material" (R/V) ratios of 100/0, 72/25, 50/50, and 0/100. The virgin asphalt grade of 150-200 A was used for all trial mix design. The characteristics of the mix at the design asphalt content for the various trial mix designs are summarized in Table 6.5.

As a result of the testing and evaluation, the recycle mix was designed for an R/V ratio of 75/25 at a total binder content of 5.2 percent by weight of dry aggregate. For this R/V ratio a virgin asphalt content of 0.7 percent was required. The virgin asphalt grade selected was a 120-150 A which was felt would result in the equivalent of a 150-200 B grade asphalt in the recycled mix. As seen in Figure 6.4, this addition is expected to decrease the penetration at 25°C and increase the viscosity at 60°C, with an improvement in temperature susceptibility.

Since the mix properties for the 75/25 and 50/50 ratios were very similar the higher ratio was selected primarily due to the obvious savings in virgin asphalt cement and aggregate.

TABLE 6.5

Summary of Trial Mix Designs - Project 2:26 & 28

R/V	100/0	75/25	50/50	0/100
Design Total A.C. %*	6.0	5.2	5.1	5.4
Design Virgin A.C. %*	-	0.7	2.1	5.4
Density	2 404	2 382	2 375	2 361
Stability N	10 617	12 250	12 250	12 875
Air Voids %	1.0	3.1	3.1	3.2
V. M. A. %	-	11.2	11.4	12.8
Flow mm	2.8	2.1	2.2	2.8
Ret. Stab. (after 24 hours soak) %	-	93	92	98

GRADATION

Sieve Size µm	Percent Passing			
16 000	99	97	97	100
10 000	74	77	82	85
5 000	53	55	57	56
1 250	32	33	33	32
630	23	24	25	23
315	15	17	18	16
160	10.4	11.5	12.3	11.3
80	8.1	8.4	8.5	8.5

* Based upon dry weight of aggregate

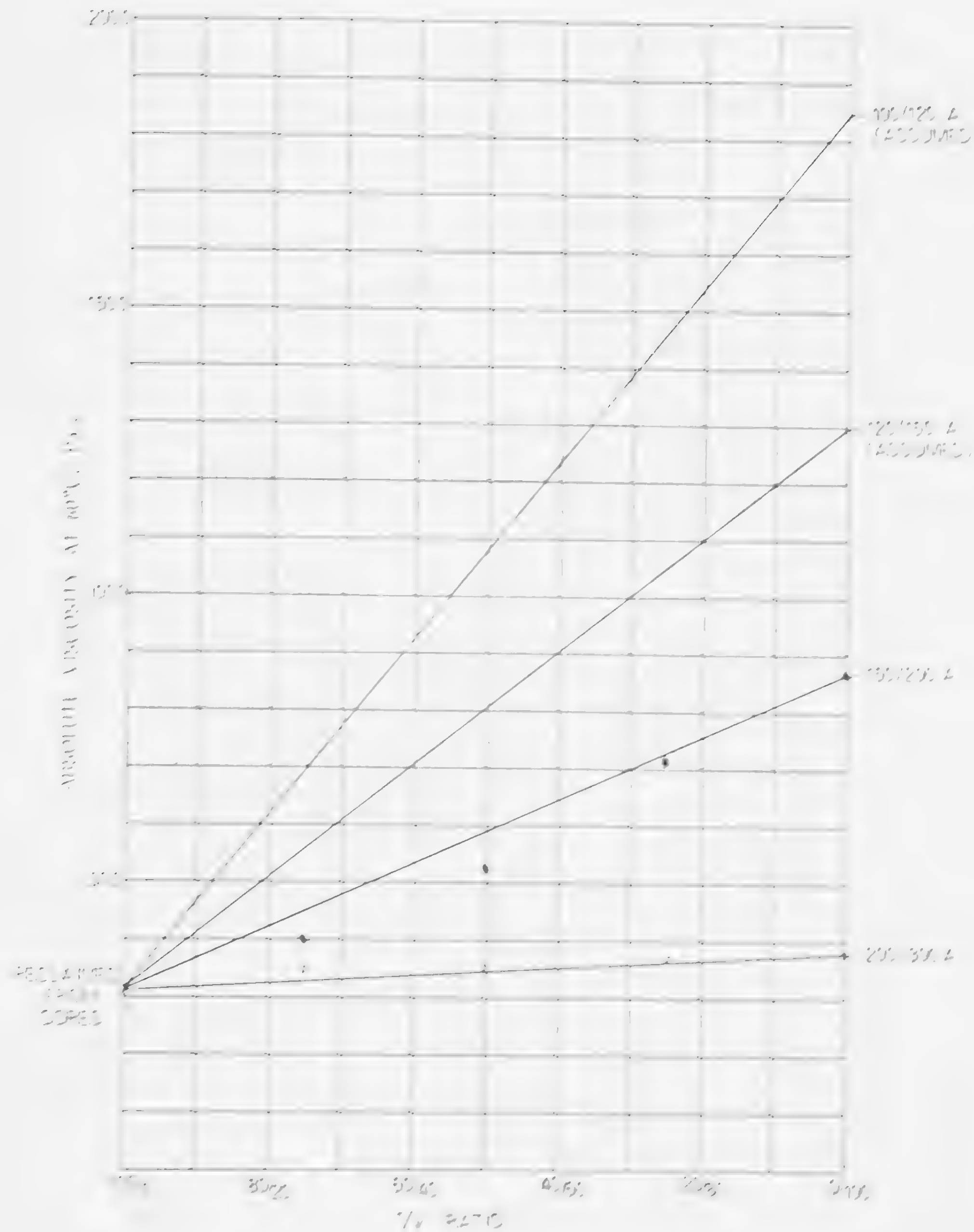


Figure 6.2 Relationship between viscosity @ 60 C and [illegible] ratio for various virgin asphalt grades, Project 2,26 & 28

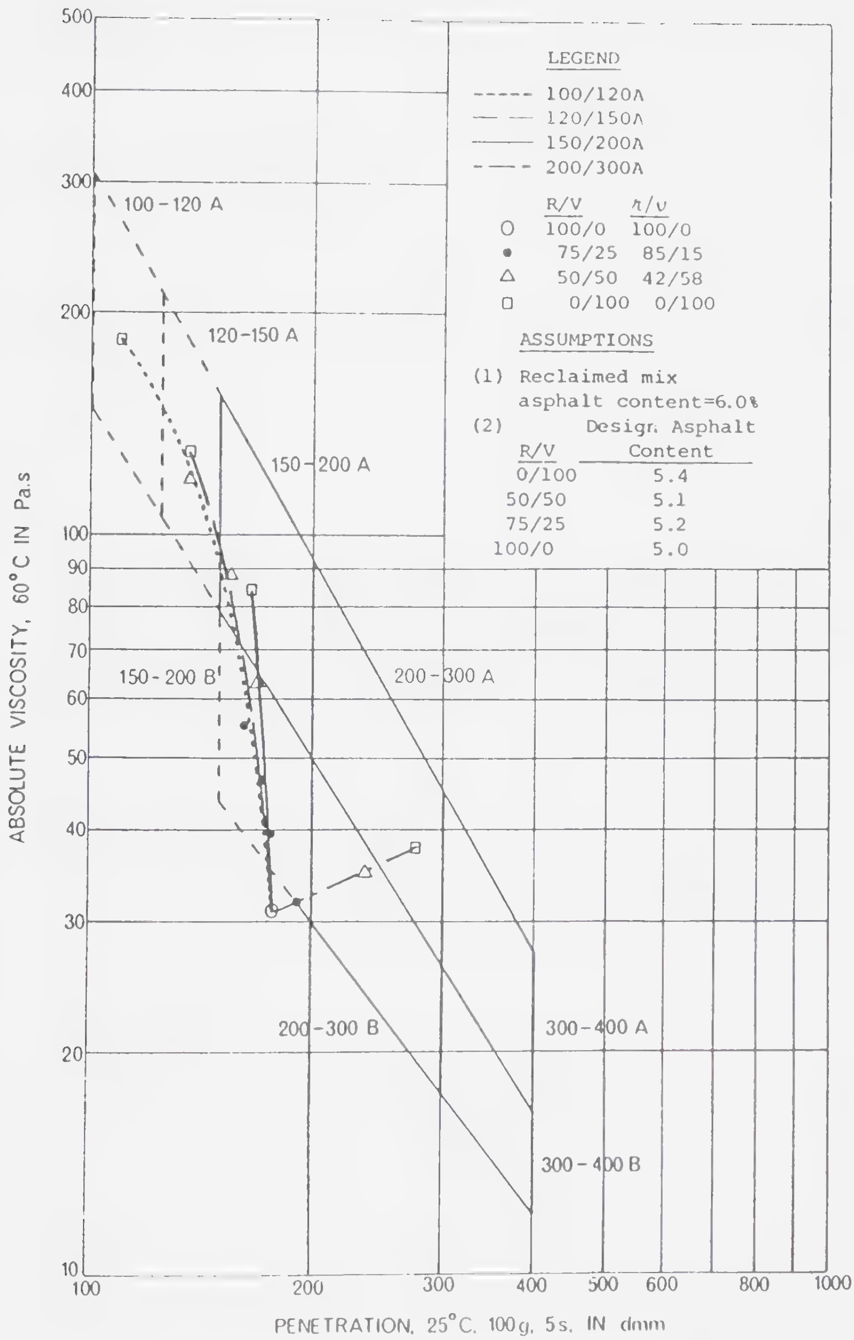


Figure 6.4 Characteristics of asphalt binder for various blends, Project 2:26 & 28 & 30

Summarized results and design curves for an R/V ratio of 75/25 are presented in Table 6.6 and Figure 6.5.

6.5 Construction

6.5.1 Recycling Methods

The recycling operation involved the reclaiming of the existing pavement to a partial depth of 40 mm and width of 3.66 m by cold milling, hauling the reclaimed asphalt pavement to the stockpile site, recycling the combined reclaimed and virgin material through a drum mix asphalt plant and placing the recycled mix to a depth of 40 mm as recycled asphalt concrete. This was then covered with a 50 mm lift of conventional ACP as a surface course.

6.5.2 Reclaiming Operations

Reclaiming involved cold-milling the existing pavement to a depth of 40 mm and width of 3.66 m (12 ft). The contractor used two CMI cold millers, one PR-450 Roto-Mill which had a 1.83 m (6 ft) mandrel, and the other a CMI Autograde PR-575 Roto-Mill which had a 2.74 m (9 ft) wide mandrel. Since only a width of 3.66 m of the existing pavement was to be cold-milled, each machine milled only 1.83 m wide strips. The two machines were operated at a close spacing in the order of 50 m apart.

The milled materials were loaded directly via a conveyor belt into trucks for transportation to the plant

TABLE 6.6

Summary of Design Recommendations Project 2:26 & 28

GRADATION			
SIEVE SIZE, µm	PERCENT PASSING		
(CGSB-8-GP-2M)	MIN.	AVE.	MAX.
16 000		97	
10 000	71	77	83
5 000	49	55	61
1 250	29	33	37
630	21	24	27
315	14	17	20
150	9.5	11.5	13.5
80	6.4	8.4	10.4

ASPHALT CONTENT	%	5.2
DENSITY	kg/m^3	2 382
STABILITY	N	12 250
AIR VOIDS	%	3.1
VOIDS MINERAL AGGREGATE	%	11.2
VOIDS FILLED WITH ASPHALT	%	73
FLOW	mm	2.1
RETAINED STABILITY (24 h SOAK)	%	93

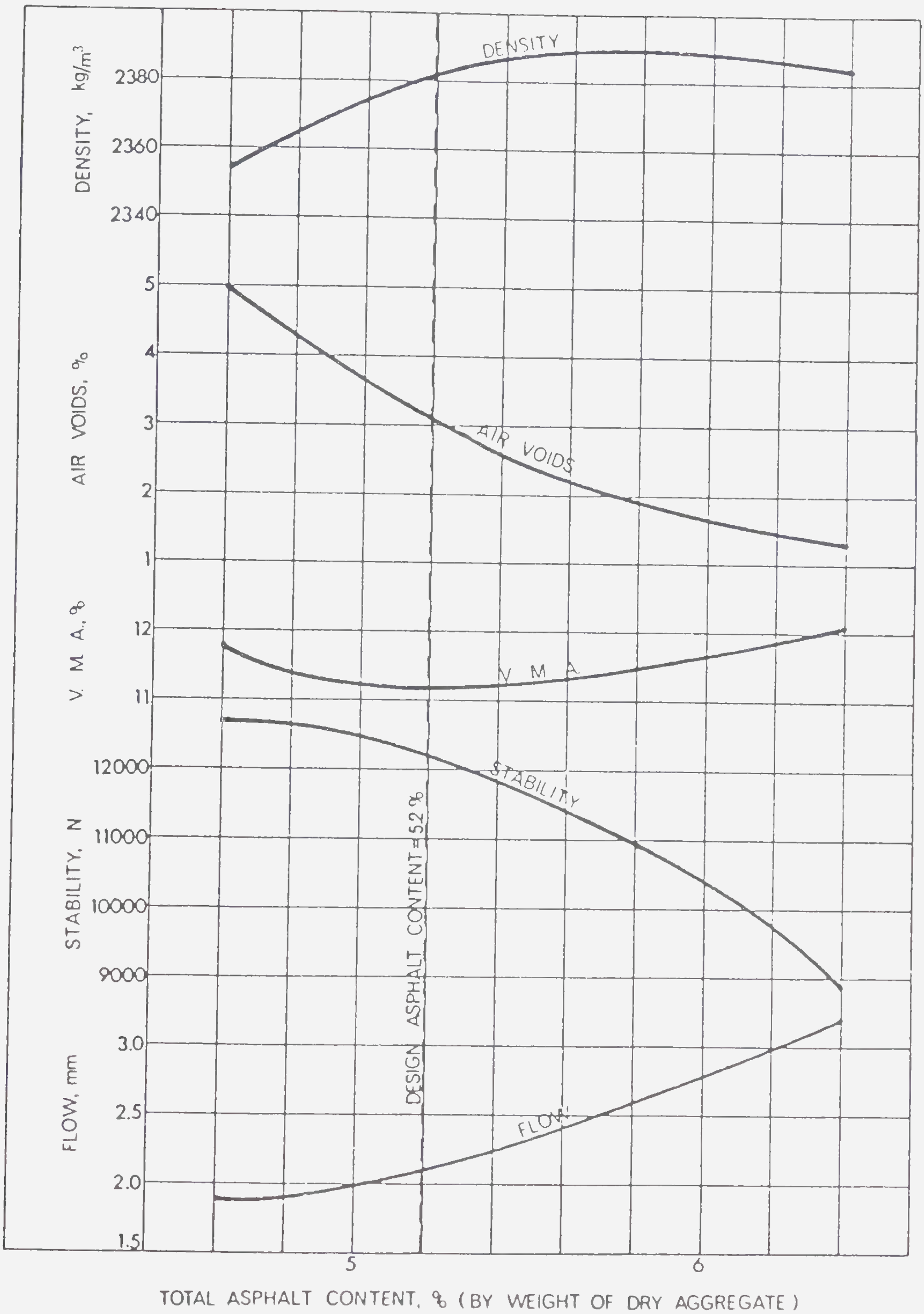


Figure 6.5 Marshall Mix Design Summary, R/V = 75/25, Project 2:26 & 28

site for stockpiling. Some fine cuttings were deposited behind the Roto-Mill on the milled surface. These fine cuttings were accumulated by the sweeper and dumped in front of the cold miller. This procedure contributed to the increase in fines content of the reclaimed material. Water was sprayed constantly in order to keep down the dust and to cool the cutting teeth.

An average of approximately 1200 tonnes of asphalt concrete pavement was reclaimed in a 10-hour working day. Each machine was operating at a speed of approximately 7 m/minute. This totalled about 3 km/day, taking the down time required for changing of the cutting teeth and other delays into account. An average of about 60 tonnes/hour of asphalt concrete pavement was reclaimed by each machine.

Cold milling started on September 16, and for the first two days confined to bridge decks and under bridges. Full scale milling was from September 20 to 27th, 1982, a period of 6 working days. During the reclaiming operation the weather was generally warm and sunny with mid-day air temperatures in the range of 11 to 22°C. In the morning, when the pavement was cooler, reclaiming of the cold pavement was slower than later in the day and the rate of tooth wear was increased. There was an observable improvement in the reclaiming operation during the warmer parts of the day.

6.5.3 Plant Operation

The hot plant and the stockpile for the reclaimed material were located near the Mix Crushed Stockpile Site in the SW 27-42-26-3. The aggregate from the Mixed Crushed Stockpile was used as the virgin aggregate for this project. A granular base was constructed for the reclaimed asphalt concrete stockpile. This stockpile was kept to a maximum height of 3 m to avoid consolidation during warm weather and segregation. A conveyor belt was not used for stockpiling, however, this did not appear to cause a problem.

The contractor employed a 400 tonne/hour Boeing Drum Mix Plant equipped with a specially designed Pyrocone to protect the reclaimed asphalt concrete from direct contact with the burner flame.

The reclaimed asphalt concrete and the virgin aggregate were removed from the stockpile with a front end loader and placed into separate cold storage bins. From the bins both the RAP and virgin aggregate were fed into the front of the drum by a conveyor belt, after passing through a grizzly screen to remove oversize particles. The drum was inclined at a slope of 3.0 degrees to the horizontal. The proportioning of the reclaimed asphalt concrete and the virgin aggregate was done by conveyor belt scales. The new asphalt was added near the mid-point of the drum. The final recycled mix was then discharged into the hot elevator at the rear of the drum and transported up into a storage silo. The temperature of the final mix was displayed in the

control room.

A slight amount of water, approximately 1.8 percent by weight was added to the cold feed at its point of entry into the drum mixer, to help control stack emissions. However, the amounts of dust and blue smoke produced were considerably higher than with conventional asphalt concrete mix.

Actual measurements of the stack emissions for particulate and opacity requirements were not taken, however the comparative appearances of the exhaust discharges for the recycled and conventional mixes were distinct.

The plant was operated at a production rate of approximately 210 tonne/hour. It was noticed that as the production rate increased to about 280 tonne/hour, the amount of dust and blue smoke increased considerably.

The average recycled mix temperature was about 140°C, however, slight fluctuations in the mix temperature were noticeable.

6.5.4 Paving

Paving of the recycled asphalt concrete mixture commenced on September 20th and was completed on September 27th, 1982, a period of six working days. The recycled asphalt concrete was about 7 000 tonnes in total, for an average of 1 170 tonnes per day.

A special provision in the contract required that after removal of the existing asphalt concrete pavement and

cleaning of all dirt and debris from the cold milled surface, a tack coat was to be applied. The recycled asphalt concrete was to be placed after a curing period of not less than one hour.

Initially a tack coat of diluted SS-1 emulsified asphalt was applied, however after the first day it was decided to omit the tack coat application for the remainder of the project. Delays to the paving operation and the milled surface being deemed sufficiently rough were some of the factors considered by District personnel in reaching this decision.

The contractor used a Barber Green SB-131 Paver for laying the mix, and two Dynapac dual drum vibratory steel rollers CC42A and CC50A for compaction.

Visually, the recycled mix placed on the road appeared satisfactory. It seemed to be well coated and to contain the proper amount of asphalt cement. Not much difference between the conventional and the recycled mix could be detected. Also the recycled mix was similar in handling to the virgin mixes when placed through the paver. The recycled mix was observed to be very stable under rolling, with no slippage evident.

In some instances oversize stone particles, larger than 16 000 μm were dragged along by the paver screen and had to be manually removed and mix replaced prior to breakdown rolling.

It was observed that the recycled asphalt concrete mix cooled faster than virgin mixes. This could be due in part to the use of the Pyrocone, which prevented direct contact of the burner flame with the virgin aggregate and reclaimed asphalt concrete.

In view of the apparent success with the R/V ratio of 75/25, it was decided to try a short section of 85/15. On September 23, a section of the northbound travelling lane between station 7+660 and station 7+860 was paved with this ratio (Unit 24R). No virgin asphalt was added, since the asphalt content at this ratio was in the same order of the optimum asphalt content required.

This trial was not satisfactory due to the following reasons:

1. Blue smoke increased significantly, which was not desirable,
2. The mix appeared to lack cohesion under rolling,
3. Cracks appeared on the mat after the roller had passed, and
4. The pavement started ravelling almost immediately.

On September 27, recycle mix with R/V = 75/25 was used for the top lift on a short test section on southbound passing lane between station 8+440 and station 8+920 (Unit 34R). The virgin asphalt cement added was 1.0 percent, bringing the total asphalt content to 5.5 percent. Despite this being slightly over the design value the recycled mix appeared to contain the proper asphalt content. No

difference in appearance between the conventional mix and the recycled mix was observed. The mix was very stable under rolling. This section will be evaluated by periodic observations of surface condition.

Ravelling of the tapered joint at the start of this section was observed shortly after construction. This condition did not develop throughout the section and hence it can be attributed to faulty methods in constructing the joint.

6.6 Test Procedures

The testing operation for the recycling project was performed by two separate laboratory services, the field laboratories located at the plant site and the Central Laboratory of Alberta Transportation located at Edmonton.

The field laboratories were used for process control and consisted of two mobile units, one from the District and the other was the special projects lab from the Central Laboratory Testing Services. The two mobile labs worked in conjunction and performed the following control tests and inspection:

(a) Virgin Aggregate:

- sieve analysis,
- moisture content.

(b) Reclaimed Asphalt Pavement:

- Determination of asphalt content by nuclear gauge,

- Reflux extraction:
  - asphalt content
  - sieve analysis,
- Moisture content.

(c) Recycled Mix:

- Air voids and density of field laboratory compacted specimen.
- centifuge extraction:
  - asphalt content
  - sieve analysis,
- Reflux extraction:
  - asphalt content
  - sieve analysis,
- Moisture content.

(d) Plant Checks:

- Asphalt content based on bulk quantities,
- Production rate,
- Recycled mix discharge temperatures.

(e) Road Inspection:

- Placing and compaction temperatures,
- Compaction equipment and rolling patterns.

(f) Compaction and air voids based on cored samples.

The Alberta Transportation Laboratory at Edmonton, performed the following tests on samples submitted from each production unit:

1. Recovery of asphalt by the Abson method from solutions

extracted from the RAP and recycled asphalt concrete,

2. Penetration and viscosity tests on the recovered asphalt, and
3. Sieve analysis on the recovered aggregate.

6.7 Test Results

6.7.1 Field Laboratory Results

The results given in this section are based on the field laboratory tests obtained during construction. Tables 6.7 to 6.13 summarize these test results.

Table 6.7 shows the temperature observed at various stages of construction. The average drop in temperature between discharge and placing, observed just behind the paver, was 14°C with a standard deviation of 7.2°C.

Table 6.8 gives a summary of the compaction data for the recycled asphalt concrete. The average compaction achieved on this project was 95.0 percent with a standard deviation of 1.8 percent. Figure 6.6 shows a histogram and frequency distribution of these compaction data. According to contract specifications the asphaltic mixture should have been compacted to an average density of at least 97.0 percent and a minimum density of 95 percent at all locations. The achieved average compaction is about 2.0 percent lower than the specificed compaction.

In order to determine whether the low density could be a result of factors relating to the recycling operation

TABLE 6.7

Temperature Variations for Recycle Asphalt Concrete Pavement, Project 2:26,2:28

Date	Time	Unit #	Temperature °C			
			Discharge mix @ plant	Placing	Breakdown	Air
20-09-82	12:00	12R	140	110	110	13
	14:00	13R	120	103	105	16
	16:00	14R	134	122	117	20
	18:30	15R	140	125	120	17
21-09-82	11:30	16R	135	128	120	11
	15:50	17R	139	125	125	18
	18:00	18R	138	126	120	18
22-09-82	12:20	20R	141	130	130	12
	17:00	21R	141	125	120	19
	18:30	22R	148	129	126	17
23-09-82	12:30	24R*	143	122	-	12
	15:00	25R	139	135	125	22
24-09-82	13:50	28R	149	-	-	16
	15:30	29R	143	121	116	18
27-09-82	14:05	32R	-	145	135	16
	16:00	33R	138	-	-	19
	18:00	34R*	145	140	135	17

* Test Section, N.B. Travelling lane with R / V= 85 / 15

** Test Section, S.B. Passing lane, "Top Lift"

TABLE 6.8

Compaction Summary - Project 2:26,2:28

Date	Formed Specimen (Marshall)			Field Densities - Cores				% Compaction
	Unit #	Density kg/m^3	Air Voids %	Unit #	Thickness mm	Density kg/m^3	Air Voids %	
20-09-82	12R	2328	6.0	12R	35	2168	12.4	93.1
	13R	2364	3.6	13R	33	2136	13.0	90.3
	14R	2365	4.1	14R	40	2255	8.6	95.3
	15R	2363	4.7	15R	38	2208	10.9	93.4
				15R	42	2197	11.5	93.0
21-09-82	16R	2374	3.6	16R	50	2246	8.9	94.6
				16R	34	2209	10.3	93.1
	17R	2369	3.9	17R	50	2299	6.8	97.0
				17R	50	2224	9.8	93.9
				17R	48	2203	10.2	93.0
	18R	2375	3.3	18R	50	2241	8.8	94.6
				18R	45	2248	8.4	94.7
				18R	40	2210	10.0	93.1
22-09-82	20R	2367	4.0	20R	45	2314	6.1	97.8
				20R	45	2277	7.6	96.5
	21R	2388	3.1	21R	45	2348	4.6	98.3
				21R	50	2289	7.0	95.9
	22R	2357	3.6	22R	50	2284	7.1	96.9
				22R	45	2201	10.7	93.4
23-09-82	24R*	2385	3.9	24R	40	2222	10.3	93.3
				24R	45	2343	5.2	98.4
				24R	45	2255	8.2	94.3
				24R	50	2324	5.3	97.2
				24R	45	2321	5.6	97.0
	25R	2399	2.5	25R	40	2244	8.6	93.8
				25R	45	2283	7.0	95.4
				25R	40	2208	10.0	92.3

TABLE 6.8

Compaction Summary - continued

Date	Formed Specimen (Marshall)			Field Densities – Cores				% Compaction
	Unit #	Density kg/m³	Air Voids %	Unit #	Thickness mm	Density kg/m³	Air Voids %	
24-09-82	28R	2375	3.3	28R	38	2246	8.6	94.6
				28R	40	2254	8.2	94.9
				28R	40	2276	7.4	95.8
	29R	2367	4.6	29R	50	2260	8.9	95.5
				29R	50	2254	9.1	95.2
				29R	45	2274	8.3	96.1
27-09-82	32R	2347	5.2	32R	40	2252	9.2	96.0
				32R	40	2248	9.8	95.2
				32R	50	2265	8.6	96.5
	33R	2358	4.4	33R	40	2267	8.4	96.1
				33R	40	2247	9.0	95.3
	34R**	2374	3.7	34R	50	2258	8.4	95.1
				34R	60	2214	10.2	93.3
				34R	60	2278	7.6	95.6
Average		2368	4.0		44	2253	8.6	95.0
S.D.		16	0.8		5	45	1.9	1.2
No.		16	16		38	38	38	38

* Test Section, N.B. Travelling lane with R / V = 85 / 15

** Test Section, S.B. Passing lane, Top Lift

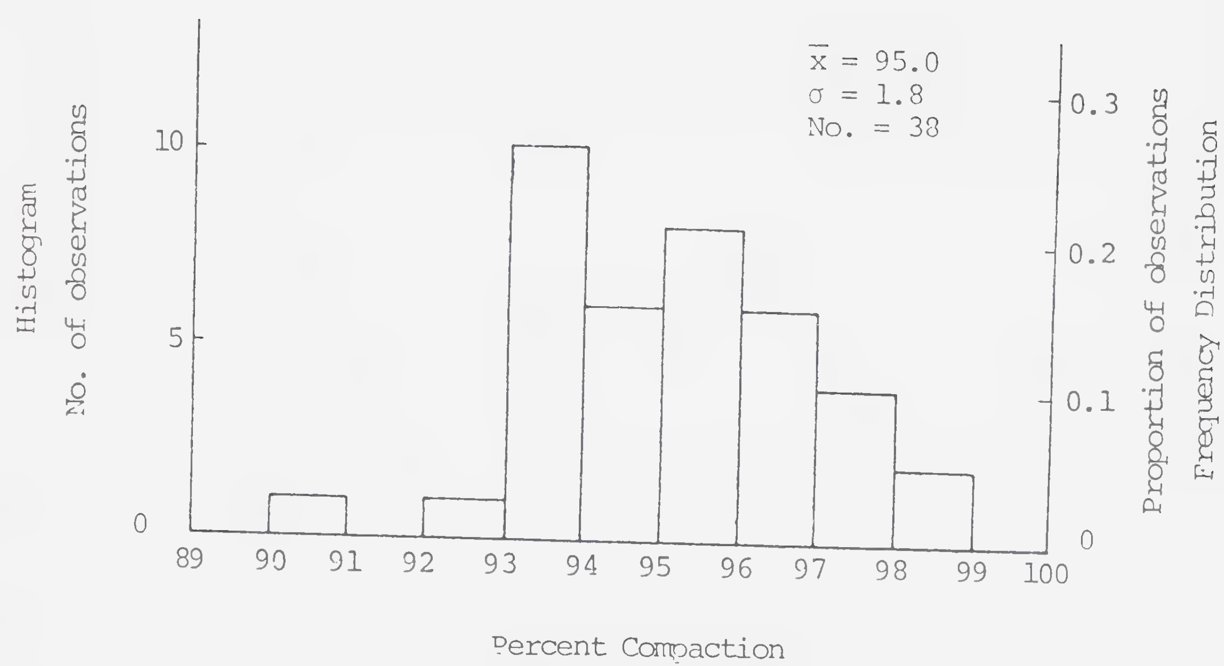


Figure 6.6 Histogram and frequency distribution of compaction data for recycled asphalt concrete. Project 2:26, 2:28.

only, an analysis of compaction data for the conventional asphalt concrete surface course placed on the same project was made. Figure 6.7 presents these results in the same form of histogram and frequency distribution. The average compaction achieved on the ACP surface course was 95.0 percent also, with a standard deviation of 1.2 percent, slightly lower than for the recycled pavement. Comparison of the two histograms shows that the compaction of the recycled mix is not normally distributed, with a larger number of observations in the density range below 94.0 percent. Although the average densities are the same, the variability in compaction of the recycled mix is more than that of the conventional ACP. One of the main reasons for this could be more rapid cooling and fluctuations in the temperature of the recycled mix. Additional compactive effort in response to quality control testing on the project could have improved the overall results.

Table 6.9 summarizes the asphalt content determinations for the reclaimed asphalt concrete and recycled mix for each production unit. Previous control laboratory extractions on core samples had indicated an asphalt content of 6.0 percent. Due to time limitations only four extractions based on the reclaimed material were performed in the field.

Based on the value of 6.0 percent and a R/V ratio of 75/25, the plant controls were set for the addition of 0.7 percent new asphalt cement. Exceptions to this were for unit 34R and 24R. Unit 34R was a section of top lift which was to

TABLE 6.9

Field Determination of Asphalt Content
Project 2:26, 2:28

Date	UNIT #	Reclaimed A.C. %		Recycled Mix A.C. %		
		Uncorrected Centrifuge	Reflux	Uncorrected Centrifuge	Ash Corrected Centrifuge	Nuclear
20-09-82	12R	----	----	----	----	4.6
	13R	----	----	6.0	5.3	5.3
	14R	6.6	----	----	----	4.9
	15R	----	----	----	----	4.5
21-09-82	16R	6.3	----	5.3	4.8	5.0
	17R	----	5.6	5.7	5.1	4.9
	18R	----	----	6.0	5.2	5.2
22-09-82	20R	----	----	5.3	4.5	4.9
	21R	----	5.9	5.7	5.0	5.0
	22R	----	----	6.0	5.0	5.1
23-09-82	24R	----	----	5.3	4.6	4.7
	25R	----	----	5.8	5.0	5.2
24-09-82	28R	----	----	5.0	----	----
	29R	----	----	5.7	5.0	4.5
27-09-82	32R	----	----	----	----	4.6
	33R	----	----	----	----	4.9
	34R	----	----	----	----	5.7
Average		6.5	5.8	5.6	5.0	4.9
S.D.		N/A	N/A	0.3	0.2	0.2
No.		2	2	11	10	15

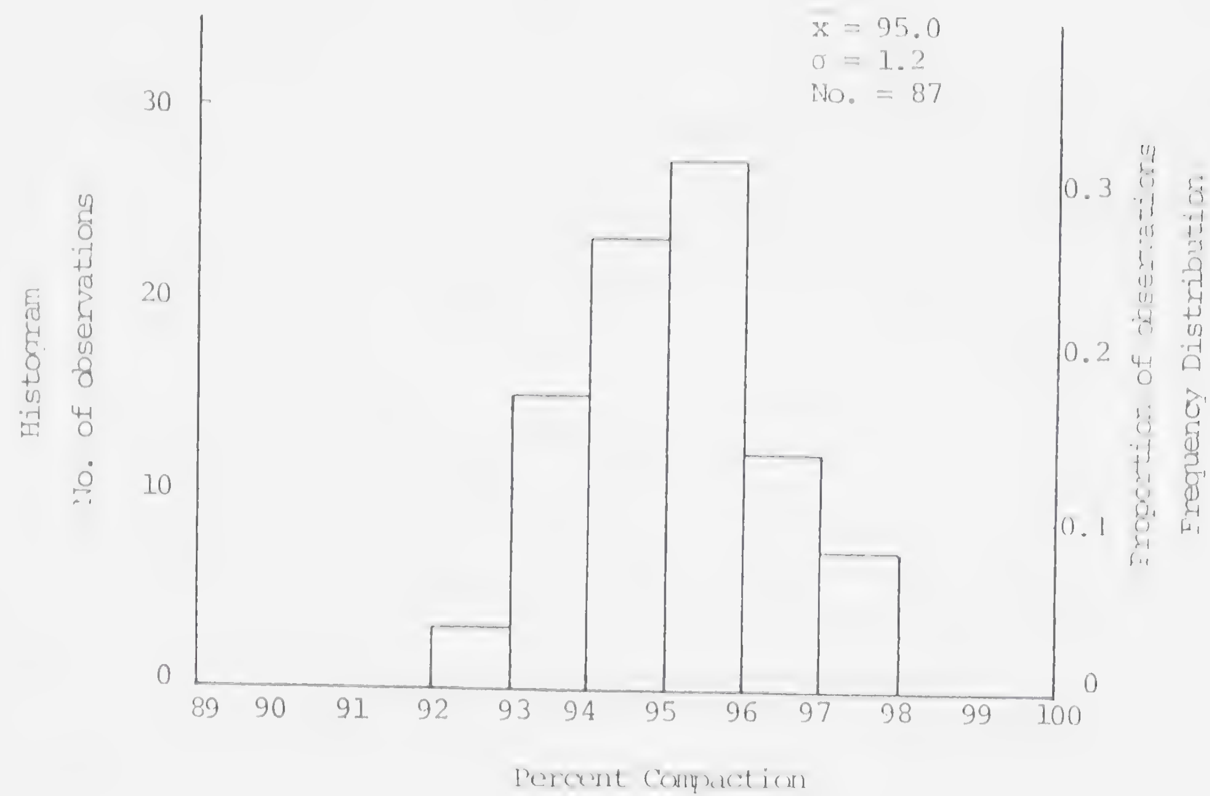


Figure 6.7 Histogram and frequency distribution of compaction data for asphalt concrete surface course. Project 2:26, 2:28.

be left exposed to traffic. Slightly increased binder content was considered desirable so 1.0 percent asphalt cement was added. Unit 24R was a short trial section in which an R/V of 85/15 was used. At this high ratio it was decided not to use any additional asphalt cement.

The asphalt content of the recycled mix, based on the corrected centrifuge results, averaged 5.0 percent with a standard deviation of 0.2 percent. The nuclear results were very similar and averaged 4.9 percent, with the same standard deviation. Air voids were calculated using the nuclear results.

The average asphalt content of the recycled mix was 0.2 percent less than the design asphalt content, despite the addition of 0.7 percent new asphalt cement as recommended. This is probably due to a slightly lower asphalt content in the RAP. Limited data presented in Table 6.9 tends to confirm this suggestion.

Tables 6.10 to 6.12 present gradations of virgin aggregate, RAP and recycled mixes respectively.

Table 6.13 gives a comparison of gradation results for cores and cold-milled reclaimed asphalt concrete. It can be seen that there has been a significant increase in the amounts passing each sieve size due to the cold milling operation. The amount passing 5 000 μm size increased by 12 percent, the 315 μm size by 6 percent and passing the 80 μm by 1.3 percent, based on average results.

TABLE 6.10

Gradation of Virgin Aggregate From Mix Pit

Project 2:26, 2:28

Unit	Percent Passing							Moisture Content
#	16 000 µm	10 000 µm	5 000 µm	1 250 µm	315 µm	160 µm	80 µm	%
13R	100	87	62	36	15	11	8.1	7.4
14R	100	87	54	32	15	10	7.0	6.2
15R	100	86	59	37	17	11	6.9	7.0
16R	100	87	54	32	14	9	6.6	5.3
17R	100	83	56	34	15	9	5.9	5.7
20R	100	80	51	30	12	8	5.8	6.9
21R	100	80	51	29	13	12	6.4	5.1
25R	100	86	63	38	17	12	9.3	7.3
28R	100	82	58	35	16	11	7.5	7.5
29R	100	87	58	36	18	13	9.3	6.4
33R	99	91	65	40	19	14	10.1	6.2
Average	100	85	57	34	16	11	7.5	6.5
S.D.	0.3	3.3	4.5	3.3	2.0	1.7	1.4	0.8
No.	11	11	11	11	11	11	11	11

TABLE 6.11

Gradation of Aggregate Extracted by Centrifuge Extraction from Reclaimed Asphalt Concrete*

Project 2:26, 2:28

Unit #	Percent Passing							Moisture Content of Reclaimed A.C. %
	16 000 μm	10 000 μm	5 000 μm	1 250 μm	315 μm	160 μm	80 μm	
14R	100	95	73	47	23	14	8.8	1.7
16R	100	87	65	40	20	14	9.5	1.9
17R	97	87	63	36	19	13	8.8	1.1
28R	97	82	58	35	20	14	10	1.6
Average	99	88	65	40	21	14	9.3	1.6
S.D.	1.5	4.4	5.4	4.7	1.5	0.3	0.5	0.3
No.	4	4	4	4	4	4	4	4

NOTE: * Reclaiming by cold milling operation

TABLE 6.12

Gradation of Aggregate Extracted by Centrifuge Extraction from Recycled Mix

Project 2:26, 2:28

Unit #	Percent Passing							Moisture Content of Recycled Mix %
	16 000 μm	10 000 μm	5 000 μm	1 250 μm	315 μm	160 μm	80 μm	
13R	100	89	63	40	20	13	9.1	0.2
16R	100	85	55	33	16	11	7.3	0.1
17R	96	84	63	38	19	13	8.9	0.2
18R	99	90	66	40	21	14	9.8	0.2
20R	97	84	63	37	19	13	9.0	0.5
21R	98	85	64	38	19	13	8.9	0.5
22R	99	87	66	40	20	14	9.7	0.6
24R	95	82	58	35	18	12	8.4	0.1
25R	94	83	59	35	19	14	9.7	0.3
28R	98	82	55	33	17	12	10.3	0.3
29R	96	83	60	36	18	12	8.0	-
Average	97	85	61	37	19	13	9.0	0.3
S.D.	1.9	2.6	3.8	2.5	1.3	0.9	0.8	0.2
No.	11	11	11	11	11	11	11	11

TABLE 6.13

Comparison of the Average Gradation Results of Reclaimed Aggregate from CORES and COLD-MILLED Material Project 2:26, 2:28

Sieve Size µm	Percent Passing			
	Reclaimed Aggregate (CORES)		Reclaimed Aggregate (COLD-MILLED)	
	Average	S.D.	Average	S.D.
16 000	99	0.3	99	1.5
10 000	74	4.0	88	4.4
5 000	53	2.7	65	5.4
1 250	32	1.3	40	4.7
315	15	0.9	21	1.5
160	10.4	1.0	14	0.3
80	8.4	0.5	9.3	0.5

It is desirable that the laboratory mix design should be based on gradations representative of the cold-milled pavement. If at all possible, future recycling projects should have mix designs based on actual cold milled materials.

Table 6.14 shows the production data for the recycling portion of the project. Approximately 7 350 tonnes of RAP and 7 000 tonnes of recycled mix were produced. Almost 19 km of recycled asphalt pavement were constructed.

6.7.2 Central Laboratory Tests

The following tables present the test results obtained at the Central Laboratory of Alberta Transportation Testing Services in Edmonton.

Tables 6.15 to 6.17 show the recovered asphalt properties for the reclaimed, recycled and virgin asphalt concrete for the project. The tests performed on the recovered asphalt cement included absolute viscosity at 60°C, kinematic viscosity at 135°C and penetration at 25°C.

The average values have been recalculated after excluding some obviously invalid data reported by the Central Laboratory. It appears that there may have been incomplete removal of the extraction solvent for the results reported as "too soft" or those having very low viscosity or high penetration. ASTM D1856-79 recommends that for each new supply of solvent a blank should be run on an asphalt of known properties. This could provide a useful check on the

TABLE 6.14

Production Data

Project 2:26, 2:28

Date	Reclaimed Asphalt Concrete Tonne	Recycled Asphalt Concrete Tonne	Recycled Asphalt Concrete Km
16-09-82	173.11*	----	----
17-09-82	376.63*	----	----
20-09-82	1164.34	1153.56	3.40
21-09-82	1401.78	1502.89	3.90
22-09-82	1343.22	1280.06	3.28
23-09-82	1117.28	1087.31	3.06
24-09-82**	772.93	749.10	1.84
27-09-82	994.86	1227.87	3.28
TOTAL	7344.15	7000.79	18.76†

* Reclaiming of the asphalt concrete pavement under the flyover.

** Early shut down of operation due to Friday's heavy traffic.

† Total length of recycled asphalt concrete pavement including the top lift on southbound passing lane.

TABLE 6.15

Recovered Asphalt from Reclaimed Asphalt Concrete

Project 2:26, 2:28

Unit #	Asphalt Content %	Tests on Recovered Asphalt		
		Absolute Viscosity At 60°C	Kinematic Viscosity At 135°C mm^2/s	Penetration At 25°C dmm
17R	5.9	35.7	201	178
18R	6.0	7.6	108*	250+*
20R	5.8	21.0*	159*	262+*
21R	6.4	66.1	268	150
22R	5.7	41.5	189	190
25R	6.5	79.1	274	148
28R	5.8	17.7	176	234
29R	5.6	29.9	205	155
32R	5.3	31.5	189	195
33R	3.5*	46.7	215	119
Average	5.9	43.5	215	171
S.D.	0.4	18.9	34.4	35.6
No.	9	8	8	9

* Data excluded from average

TABLE 6.16

Recovered Asphalt from Recycled Asphalt Concrete
Project 2:26, 2:28

Unit #	Asphalt Content %	Tests on Recovered Asphalt		
		Absolute Viscosity at 60°C Pa.s	Kinematic Viscosity At 135°C mm^2/s	Penetration at 25°C dmm
17R	5.5	44.9	236	164
18R	5.6	48.8	234	149
20R*	5.5	5.4*	102*	too soft
21R	5.8	146.8	386	131
22R*	6.0	14.8*	167*	288+*
25R	5.8	53.3	252	146
28R	5.3	42.7	248	184
29R	5.1	65.4	266	114
32R	5.5	52.9	261	146
33R	5.5	4.0*	93*	too soft
Average	5.5	65.0	269	148
S.D.	0.2	34.1	39.0	20.7
No.	7	7	7	7

* Data excluded from average

TABLE 6.17

Recovered Asphalt from Virgin Asphalt Concrete
Project 2:26, 2:28

Unit	Asphalt Content %	Tests on Recovered Asphalt		
		Absolute Viscosity at 60°C Pa.s	Kinematic Viscosity at 135°C mm^2/s	Penetration at 25°C dmm
36A	6.2	113.9	340	139
47A	5.3	132.2	361	130
52A	5.6	138.3	361	130
53A	5.6	178.9	402	100
55A	5.5	147.8	395	123
58A	6.2	165.5	399	111
72A*	5.7	12.2	47	too soft
73A	6.0	163.6	357	116
82A	5.4	149.6	380	118
Average	5.7	148.7	374	121
S.D.	0.3	19.4	21.4	12.3
No.	8	8	8	8

* Data excluded from average

reliability of the procedures used for the recovery of the asphalt by the Abson method on future samples tested. Despite the exclusion of data from several of the production units, the remaining data can be considered as giving a reasonable indication of the properties of the recovered asphalt from the various mixes.

Tests on the recovered asphalt from the reclaimed asphalt concrete essentially confirm the previously obtained information on cores presented in Table 6.4. The average viscosity on the cores at 60° and 135°C is slightly higher and the penetration at 25°C is the same within the precision limits of the test. As presented in Table 6.16, the recovered asphalt cement from the recycled asphalt concrete has a slightly higher viscosity at 60°C than that predicted from Figures 6.3 and 6.4. With the exclusion of some outlier data points, the recovered asphalt cement could be considered as equivalent to a 150-200 B grade material, as predicted.

Table 6.17 shows the properties of the asphalt cement recovered from the virgin asphalt concrete used for the surface course. The average penetration at 25°C was 121 and the viscosity at 60°C was 149 Pa.s, which would meet the specifications for 120-150 A asphalt cement.

Tests on the 150-200 A asphalt cement supply samples averaged 155 for penetration at 25°C and 89.5 for viscosity at 60°C. Using these average values for the recovered and original asphalts the retained penetration would be 78

percent with a ratio of 1.7 based on viscosity. Comparable results on residues from the Thin Film Oven Test (TFOT) were 56 percent and 2.4 respectively. Very little hardening, much less than that from the TFOT, has taken place during mixing and placing of the virgin ACP. This lack of hardening may be due to the use of the Pyrocone during production of the virgin mix.

Tables 6.18 to 6.20 present the gradation of virgin aggregate, reclaimed and recycled mixes respectively, as reported by the Central Laboratory. Increased variablility in the aggregate gradation of the recycled mixes compared to the virgin mixes in evident. This trend was not noticeable in the field gradation results presented earlier in Tables 6.10 to 6.12.

6.8 General Observations and Conclusions

The first hot mix asphalt recycling project on the Provincial highway system in Alberta has been successfully designed and constructed. Improvement of riding quality of the rehabilitated section of Hwy 2:26 and 2:28 has been achieved. Performance of the recycled pavement will await future observations. The short test section constructed on the project may provide information as to the performance of recycled asphalt concrete for surface courses under particular traffic and climatic conditions in Central Alberta.

TABLE 6.18

Aggregate Gradation for Asphalt Concrete Used on Top Lift (Central Laboratory)

Project 2:26, 2:28

Unit #	Percent Passing								% Fracture
	16 000 µm	10 000 µm	5 000 µm	1 250 µm	630 µm	315 µm	160 µm	80 µm	
36A	100	84	62	39	32	24	16.1	10.5	73
47A	100	81	56	37	29	22	15.4	10.6	76
52A	100	82	59	38	31	23	16.2	10.9	74
53A	100	80	56	36	28	20	14.1	9.4	76
55A	100	84	59	39	31	23	16.2	11.0	71
58A	100	88	64	42	33	23	14.8	10.6	69
72A	100	86	62	40	32	23	14.4	10.1	76
73A	100	85	60	37	28	18	12.0	9.4	70
82A	100	83	60	40	32	23	14.4	10.2	80
Average	100	84	60	39	31	22	14.8	10.3	75
S.D.	0.6	2.5	2.7	1.9	1.9	1.9	1.4	0.6	3.4
No.	9	9	9	9	9	9	9	9	9

TABLE 6.19

Aggregate Gradation for Cold-Milled Reclaimed Material (Central Laboratory)

Project 2:26, 2:28

Unit #	Percent Passing								% Fracture
	16 000 µm	10 000 µm	5 000 µm	1 250 µm	630 µm	315 µm	160 µm	80 µm	
17R	100	90	66	37	29	20	14.0	11.4	72
18R	98	86	63	36	27	19	13.2	10.7	75
20R	100	88	70	42	31	20	15.8	12.7	85
21R	98	91	73	45	35	26	17.8	13.1	87
22R	98	85	64	37	28	21	14.6	10.1	83
25R	100	88	64	38	31	22	14.6	10.1	83
28R	97	88	68	40	31	23	15.5	12.1	92
29R	100	88	64	36	28	21	15.7	11.9	83
32R	94	76	55	32	23	16	11.4	9.1	80
33R	97	84	63	39	27	16	10.5	9.0	78
Average	98	86	65	38	29	20	14.4	11.2	82
S.D.	1.9	4.2	4.8	3.6	3.2	3.0	2.2	1.4	5.9
No.	10	10	10	10	10	10	10	10	10

TABLE 6.20

Aggregate Gradation for Recycled Mix (Central Laboratory)

Project 2:26, 2:28

Unit #	Percent Passing								% Fracture
	16 000 μm	10 000 μm	5 000 μm	1 250 μm	630 μm	315 μm	160 μm	80 μm	
17R	99	84	62	38	29	21	13.6	10.5	82
18R	99	82	63	38	29	20	12.7	10.2	73
20R	99	86	66	41	31	22	19.3	16.6	81
21R	100	96	73	47	32	16	9.9	7.2	79
22R	98	86	67	41	31	22	13.8	11.2	84
25R	98	86	64	39	30	21	15.2	11.2	83
28R	98	87	64	38	29	20	14.4	10.3	84
29R	99	84	64	39	30	21	13.8	10.9	85
32R	98	86	65	40	31	21	15.0	12.1	82
33R	100	86	66	40	30	21	14.5	11.4	82
Average	99	86	65	40	30	21	14.2	11.2	82
S.D.	0.8	3.7	3.1	2.7	1.0	1.7	2.3	2.3	3.4
No.	10	10	10	10	10	10	10	10	10

The following observations are based on an analysis of laboratory design and field construction data for this project.

1. The cold milling operation, using the CMI Roto-Mills, was successful in partial width removal of asphalt concrete pavement.
2. The amount passing all sieve sizes has been increased due to the cold milling operation compared to cores. The field measured percent increase in passing the 80 μm sieve size was 1-2 percent.
3. The 75 percent reclaimed asphalt concrete and 25 percent virgin material mixed and placed successfully, and visually appeared identical to conventional mix. The R/V ratio of 85/15 was not satisfactory.
4. The desired mix temperature was obtained with recycled mix at a R/V ratio of 75/25.
5. The recycled asphalt concrete mix apparently cools faster than virgin mixes having the same discharge temperature at the plant.
6. Compaction results for the recycled asphalt pavement indicated that an average density of 95.0 percent. was acheived, which is approximately 2 percent lower than the specified compaction. Results for the conventional ACP were of the same average density, but with slightly less variablity.
7. It appears that the variability in aggregate gradation is somewhat greater for recycled mixtures when compared

with virgin aggregate mixtures.

8. Using a 120-150 A virgin asphalt cement, the recovered asphalt cement for the R/V ratio of 75/25, was equivalent to a 150-200 B grade material.
9. Virgin asphalt concrete mixes produced with the Boeing 400 Drum Mix plant equipped with Pyrocone exhibited very little hardening, much less than that from the Thin Film Oven Test.

7. CONSTRUCTION OF RECYCLING PROJECT NO.2

7.1 General

This chapter discusses the design and construction of the recycling project on Highway 2:18; 2:20, from South of Crossfield to South of Carstairs.

This project was the second contract awarded for hot mix asphalt concrete recycling on the Provincial highway system in Alberta and was designed and constructed during the summer and fall of 1982 (32,33).

The recycling section was on the outer northbound and southbound lanes of Highway 2 from km 23.130 to km 31.189 of control section 2:18 and from km 0.000 to km 7.070 of control section 2:20. The total length of recycling was 30.258 lane-kilometers.

This highway carries heavy commercial traffic, and also recreational traffic throughout the year. In 1981 this section of the highway was determined to be carrying an Average Annual Daily Traffic of 16 000 with 15 percent trucks.

Peter Kiewit Sons Co. Ltd. of Winterburn was the prime contractor for the recycled asphalt concrete paving operation. Major equipment was a 600 tonne/hour Boeing Drum-mix Plant, a Blaw-Knox PF-180H paver, two Dynapac dual drum vibratory rollers and pneumatic tire roller.

Budd Bros. Ltd. of Calgary was the subcontractor who performed the same work for the first recycling project Hwy

2:26; 2:28. Major equipment used was a PR-575 Roto-Mill with a 1.83 m (6 ft) mandrel and a PR-450 Roto-Mill with a 2.74 m (9 ft) mandrel. Both of these cold milling machines were manufactured by CMI Corporation.

7.2 The Existing Pavement

Highway 2 is a four-lane divided highway. The cross-section generally consists of a 7.32 m wide asphalt concrete pavement with 3.05 m outside and 1.22 m of inside asphalt concrete shoulder as shown in Figure 7.1. Cold milling and recycling was confined to the outer northbound and southbound lanes.

This section of Highway 2, namely 2:18 and 2:20, was constructed in the period of 1956-1958 and was overlaid in 1970 and has the following pavement structure:

75 mm of 16 000 μm topsize asphalt concrete (1970)

100 mm of 16 000 μm topsize asphalt concrete (1957-1958)

350 mm of 40 000 μm topsize stabilized granular base course (1956-1957)

Some sections of 2:18 and 2:20 were overlaid with extensive patches totalling approximately 6 km in 1980 with 50 mm of 16 000 μm topsize asphalt concrete.

These sections are:

SBL - from km 24.097 to km 25.034 (2:18),
- from km 25.958 to km 27.561 (2:18),

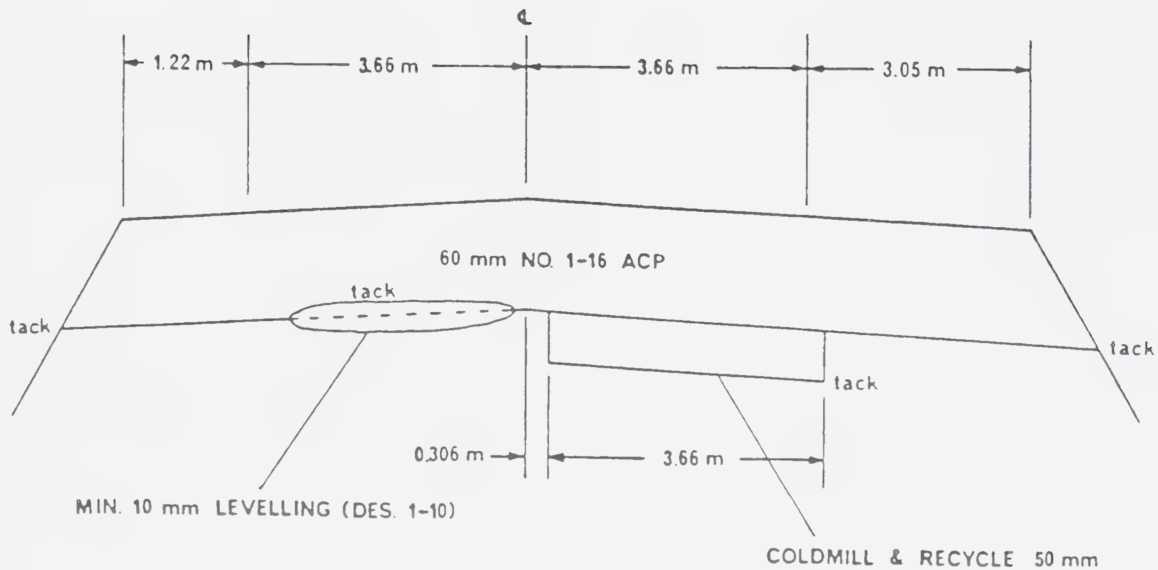


Figure 7.1 Typical cross-section - Project 2:18, 2:20

- from km 4.628 to km 6.563 (2:20).

NBL - from km 24.097 to km 25.034 (2:18),

- from km 5.978 to km 6.583 (2:20).

The condition of the existing pavement may be summarized as follows:

Northbound outer lane:

Benkelman Beam Spring rebound ($\bar{x}+2\sigma$): 1.18 mm (0.047 in) (1981)

Average RCI: 6.3 (1981)

Surface Condition: major bleeding, moderate transverse, low temperature cracking averaging 25 m spacing and an average of 20-25 mm rut depths.

Southbound outer lane:

Benkelman Beam Spring Rebound ($\bar{x}+2\sigma$): 1.14 mm (0.045 in) (1981)

Average RCI: 6.6 (1981)

Surface Condition: major bleeding, major transverse low temperature cracking averaging 15 m spacing and an average of 25-30 mm rut depths.

Table 7.1 shows the design summary of the asphalt concrete surface in 1958. The large amount passing the 80 μm sieve and the VMA of 12.5 percent can be noted. Construction reports have not been summarized in tabular form, however

they show that the asphalt content averaged 5.9 percent as compared to the design of 6.0 percent with an average of 15.8 percent passing the 80 μm sieve.

Tables 7.2 and 7.3 show the design and construction summary of the overlay placed in 1970. This overlay is of importance since it is the one that exhibited bleeding and extensive rutting. A possible contributing factor is the high asphalt content. The construction summary shows that the asphalt content was 0.9 percent above the recommended design value. The gradation was within usual job mix formula recommendations, with the exception of 2 000 μm sieve size, which was 2 percent over the suggested maximum.

Table 7.4 shows the design summary for the patched sections placed in 1980. Construction information is not available.

7.3 New Pavement Design

The existing pavement on the outer northbound and southbound lanes was to be cold-milled to a depth of 50 mm and a width of 3.66 m and replaced with recycled mix. The reason for this corrective action was severe rutting distortion in the outside lane.

Due to poor quality aggregates being used in the patched sections placed in 1980, there were to be completely removed for the entire width of highway and the reclaimed materials from those sections were not to be used for recycling. The outer lane of the same sections was then to

TABLE 7.1

Design Summary of Asphalt Concrete Surface Course

In 1958

Project 2:18,2:20

Gradation		Pit Name: Christiansen Oil Co.: Imperial Asphalt Grade: 150-200?		
Sieve Size µm	Average % Passing			
20 000	100	Suggested Asphalt	%	6.0
		Density	lbs/cu.ft.	145.7
5 000	49	Stability	lbs	2020
		Flow	0.01 Ins	14
2 000	37	Voids Mineral Agg.	%	12.5
		Voids filled with Asphalt	%	81
400	25	Air Voids	%	2.4
		Asphalt Absorption	%	1.22
80	20	Bulk Specific Grav. of Agg.		2.520
		Specific Grav. of Asphalt		1.030

TABLE 7.2

Design Summary of Overlay in 1970

Project 2:18, 2:20

Gradation		Pit Name: Kirk Asphalt Supplier: Husky Asphalt Grade: AC 27.5		
Sieve Size µm	Average % Passing			
20 000	100	Asphalt Content	%	5.7
		Density	kg/m³	2321
5 000	51	Stability	kg	1530
		Flow	mm	2.92
2 000	39	Air Voids	%	3.8
		Asphalt Absorption	%	0.65
400	25	Bulk Specific Grav. of Agg.		2.576
		Asphalt Specific Gravity		1.018
80	12.9	Retained Stability (24 hr Soak)	%	50

TABLE 7.3

Construction Summary of Overlay in 1970

Project 2:18, 2:20

Gradation				
Sieve Size μm	Average % Passing	Pit Name: Asphalt Supplier: Asphalt Grade:	Kirk Husky 200-300A	
		Average Asphalt Content	%	6.6
20 000	100	Average Density	kg/m^3	2244
5 000	55	Average Air Voids	%	5.9
2 000	45	Av. voids filled	%	67.4
400	25	with Asphalt		
80	12.2	Av. void Mineral Agg.	%	18.1

TABLE 7.4

Design Summary for Patched Sections in 1980

Project 2:18, 2:20

Gradation		Pit Name:		Carstairs Creek
Sieve Size µm	Average % Passing	Asphalt Supplier		Imperial Edmonton
		Asphalt Grade:		AC 27.5
16 000	100	Asphalt Content	%	5.9
		Density	kg/m^3	2340
10 000	76	Stability	kg	909
		Flow	mm	3.61
5 000	48	Voids Mineral Agg.	%	13.2
		Voids filled with Asphalt	%	70
2 000	32	Air voids	%	4.0
		Asphalt Absorption	%	1.62
400	24	Bulk Specific Gravity of Agg.		2.547
		Specific Gravity of Asphalt		1.030
160	19.4	Retained Stability (24 hr soak)	%	52
80	17.1			

be cold-milled to a depth of 50 mm and a width of 3.66 m. This was actually into the overlay placed in 1970.

The cold-milled area was to be shifted approximately 0.3 m off center line to the outside shoulder, in order to remove the pushed-up pavement which existed along the painted shoulder line.

The inner northbound and southbound lanes required only minor levelling. The entire roadway width would then be overlaid with one 60 mm lift of virgin mix. Reference may again be made to Figure 7.1.

7.4 Project Mix Design Procedure

The same mix design procedure as described previously in Section 6.4 was used.

The results of tests performed on cores are shown in Table 7.5. It should be noted that the recovered asphalt has a penetration at 25°C of 175 dmm and absolute viscosity at 60°C of 57.7 Pa.S. It was considered that a softening agent was not needed and a harder virgin asphalt grade was required in order to acheive a binder more resistant to rutting than the original.

After examining the results of all tests performed on cores from those section overlaid in 1980, it was decided that reclaimed material from these sections not to be recycled, hence no further tests were performed on these materials.

TABLE 7.5

Aggregate Gradation and Asphalt

Properties From Core Analysis. Project 2:18, 2:20

Gradation		Asphalt Properties	
Sieve Size µm	Average Percent Passing	Recovered Asphalt Cement %	6.2
16 000	96	Penetration @ 25°C dmm	175
10 000	77		
5 000	53	Absolute Viscosity @ 60°C Pa.s	57.7
1 250	36		
630	31	Kinematic Viscosity @ 135°C mm^2/s	--
315	23		
160	17.9		
80	14.3		

The recovered asphalt was batched together and blended at various "reclaimed asphalt to virgin asphalt ratios " (r/v) with a virgin asphalt grade of 150-200 A. These blends were tested for:

-penetration at 25°C,

-absolute viscosity at 60° and Kinematic viscosity at 135°C,

-penetration at 25°C on the residue after the Thin Film Oven Test, and

- viscosity at 60°C and 135°C on the residue after the Thin Film Oven Test.

The test results are shown in Tables 7.6 and 7.7. The penetration and viscosities for various r/v ratios were plotted on arithmetic scales and the relationship was approximately linear. With assumed characteristics of other virgin asphalt cements, estimates of the penetration and viscosities of the various blends were made without actually carrying out physical testing. Figure 7.2 shows the estimated relationship between penetration at 25°C and r/v ratio for various asphalt grades. Figure 7.3 shows the estimated relationship between viscosity at 60°C and the r/v ratio for various asphalt grades.

Figure 7.4 shows the characteristics of various blends using reclaimed asphalt from the project and four different virgin asphalt grades. It should be noted that the values shown using grades of 100-120 A and 120-150 A are only estimates.

TABLE 7.6

Penetration @ 25°C For Different r/v Ratios

Project 2:18, 2:20

Reclaim / Virgin Asphalt r / v	Penetration @ 25°C, 100 g 5S dmm		
	After Blending	Reheated	After T.F.O.T.
0/100 Virgin Asphalt 150-200 A	164	-	86
15/85	166	161	92
25/75	161	168	96
50/50	165	172	95
75/25	168	156	96
100/0 Recovered Asphalt	175	156	96

TABLE 7.7

Absolute and Kinematic Viscosity for Different r/v Ratios, Project 2:18, 2:20

Reclaim / Virgin Asphalt r / v	Viscosity; Original & Blends		Viscosity: After T.F.O.T.	
	Absolute @ $60^{O}C$ Pa.s	Kinematic @ $135^{O}C$ mm^2/s	Absolute @ $60^{O}C$ Pa.s	Kinematic @ $135^{O}C$ mm^2/s
0/100 Virgin Asphalt 150 - 200 A	85.8	295	241.2	--
15/85	92.6	291	193.2	399
25/75	82.4	277	148.4	334
50/50	80.6	267	184.5	391
75/25	93.5	294	159.7	384
100/0 Recovered Asphalt	57.7	-	148.7	365

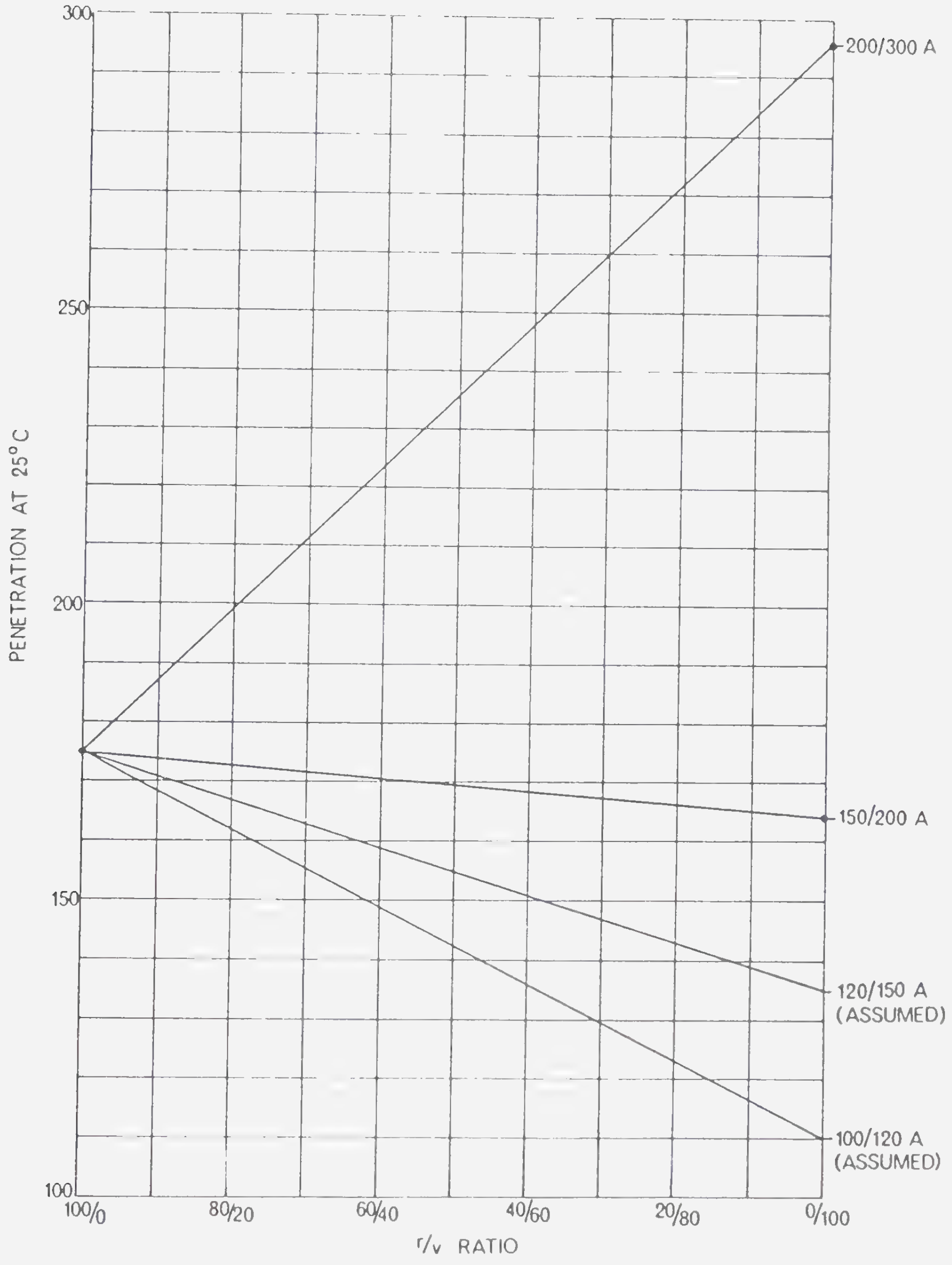


Figure 7.2 Relationship between penetration @ 25°C and r/v ratio for various virgin asphalt grades - Project 2:18, 2:20

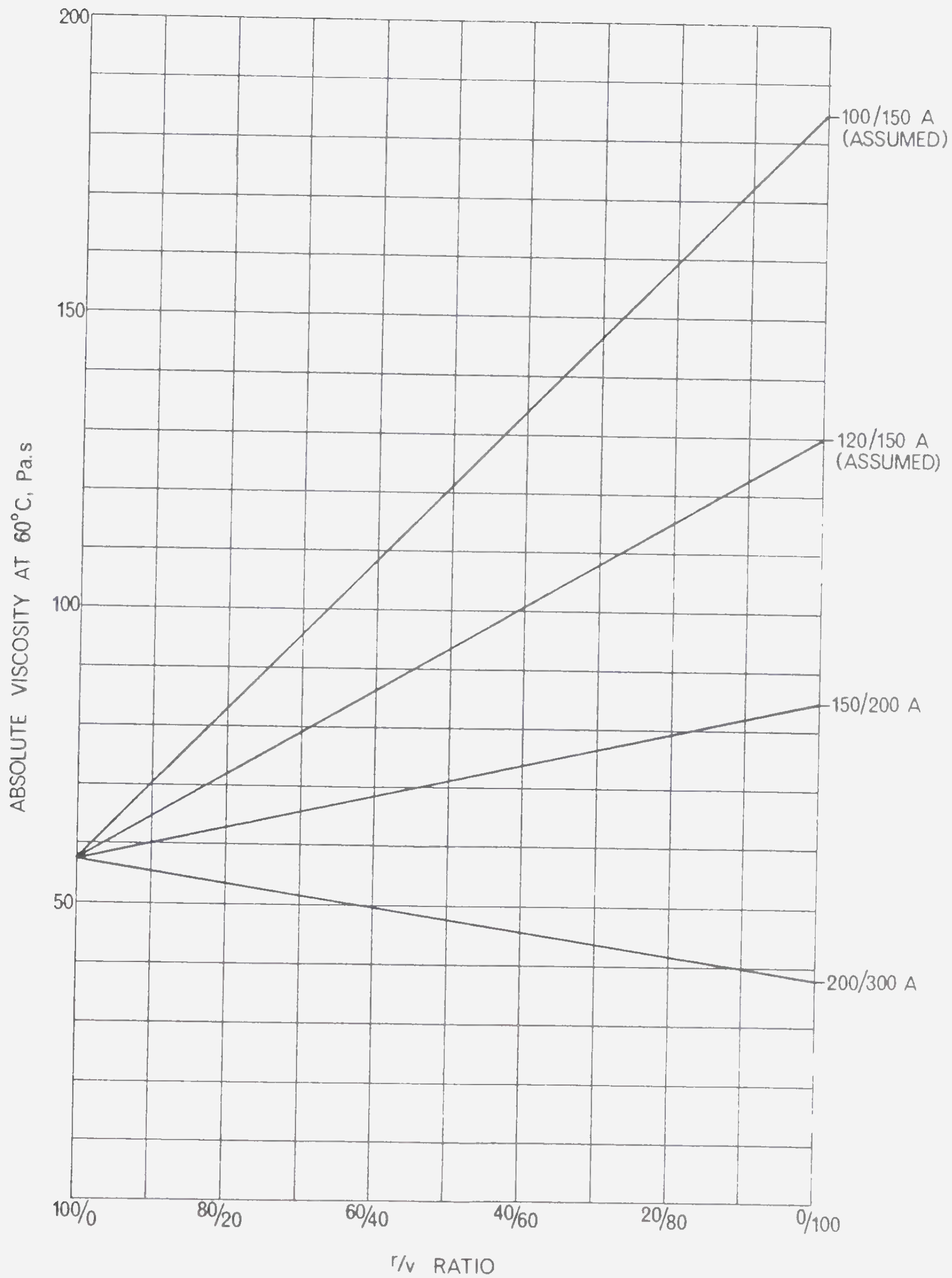


Figure 7.3 Relationship between viscosity @ 60 C and *r/v* ratio for various virgin asphalt grades - Project 2:18, 2:20

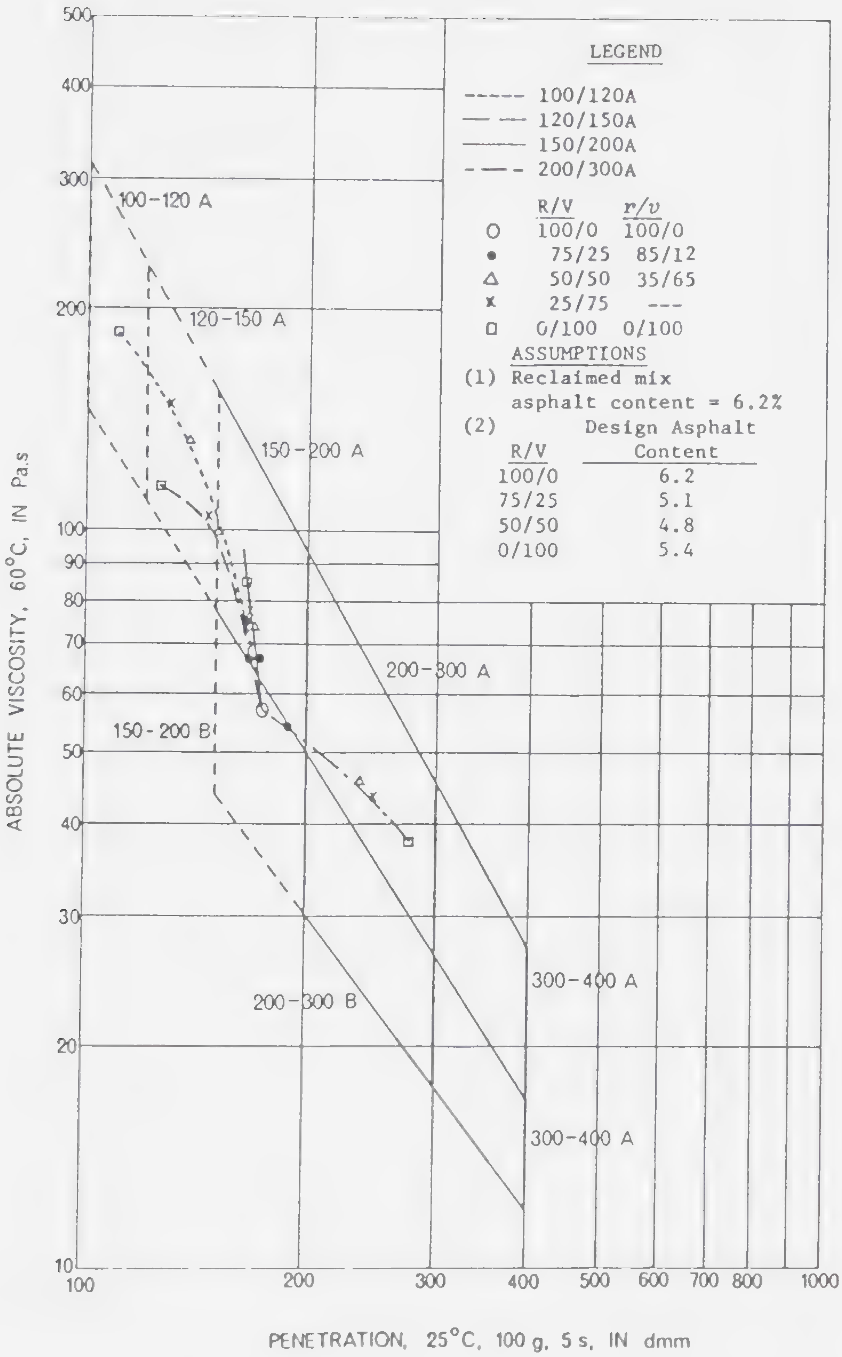


Figure 7.4 Characteristics of asphalt binder for various blends, Project 2:18, 2:20

Trial mix designs following the Marshall method were performed at various "reclaimed to virgin material" (R/V) ratios of 100/0, 75/25, 50/50, and 0/100. The virgin asphalt grade of 150-200 A was used for all trial mix designs. The characteristics of the mix at the design asphalt content for the various mix designs are summarized in Table 7.8.

As a result of the testing and evaluation, the recylced mix was designed for a R/V ratio of 50/50 at total binder content of 5.4 percent by weight of dry aggregate. Summarized results and design curves for a R/V ratio of 50/50 are presented in Table 7.9 and Figure 7.5. For this R/V ratio a virgin asphalt content of 2.2 percent was required. The virgin asphalt grade selected to be used on the project was 120-150 A which was felt would result in a 150-200 A grade asphalt in the recycled mix. As seen in Figures 7.4 and 7.5, this addition is expected to decrease the penetration at 25°C and increase the viscosity at 60°C. The selection of an R/V ratio of 50/50 was based upon several factors; the high fines content and poor quality of the reclaimed aggregate and the results of the trial mix designs.

7.5 Construction

7.5.1 Recycling Method

The recycling operation involved the reclaiming of the existing pavement to a partial depth of 50 mm and width of

TABLE 7.8

Summary of Trial Mix Design - Project 2:18, 2:20

R/V	100/0	75/25	50/50	0/100
Design Total A.C. %*	6.3	5.1	4.8	5.4
Design Virgin A.C. %*	-	0.4	1.7	5.4
Density	2 376	2 396	2 395	2 362
Stability N	9 140	14 500	13 900	8 725
Air Voids %	1.1	3.0	3.1	3.6
V. M. A. %	-	11.5	11.3	13.0
Flow mm	4.1	3.3	2.7	1.9
Ret. Stab. (after 24 h soak) %	-	80	87	70

GRADATION

Sieve Size μm	Percent Passing			
16 000	96	98	100	100
10 000	77	79	83	83
5 000	53	55	60	59
1 250	36	36	37	34
630	31	29	30	24
315	23	21	20	13
160	17.9	16.3	14.3	8.6
80	14.3	12.7	10.2	6.4

* Based upon dry weight of aggregate

TABLE 7.9

Summary of Design Data and Recommendation for a R/V Ratio of 50/50 - Project 2:18, 2:20

AGGREGATE:	
% Fracture By Weight (2 faces)	82
Bulk Specific Gravity	2.576
Asphalt Absorption	1.47%
Sand / Filler Ratio	3.0

ASPHALT:	
Type & Grade	150 - 200 A
Supplier	Husky
Location	Lloydminster
Specific Gravity	1.031

GRADATION

SIEVE SIZE, µm	PERCENT PASSING		
(CGSB-8-GP-2M)	MIN.	AVE.	MAX.
16 000		99	
10 000	76	82	88
5 000	51	57	63
1 250	31	35	39
630	25	28	31
315	18	21	24
150	14.0	16.0	18.0
80	12.2	14.2	16.2

ASPHALT CONTENT	%	5.4
DENSITY	kg/m^3	2 389
STABILITY	%	17 900
AIR VOIDS	%	3.4
VOIDS MINERAL AGGREGATE	%	12.0
VOIDS FILLED WITH ASPHALT	%	72
FLOW	mm	2.9
RETAINED STABILITY (24 h SOAK)	%	79

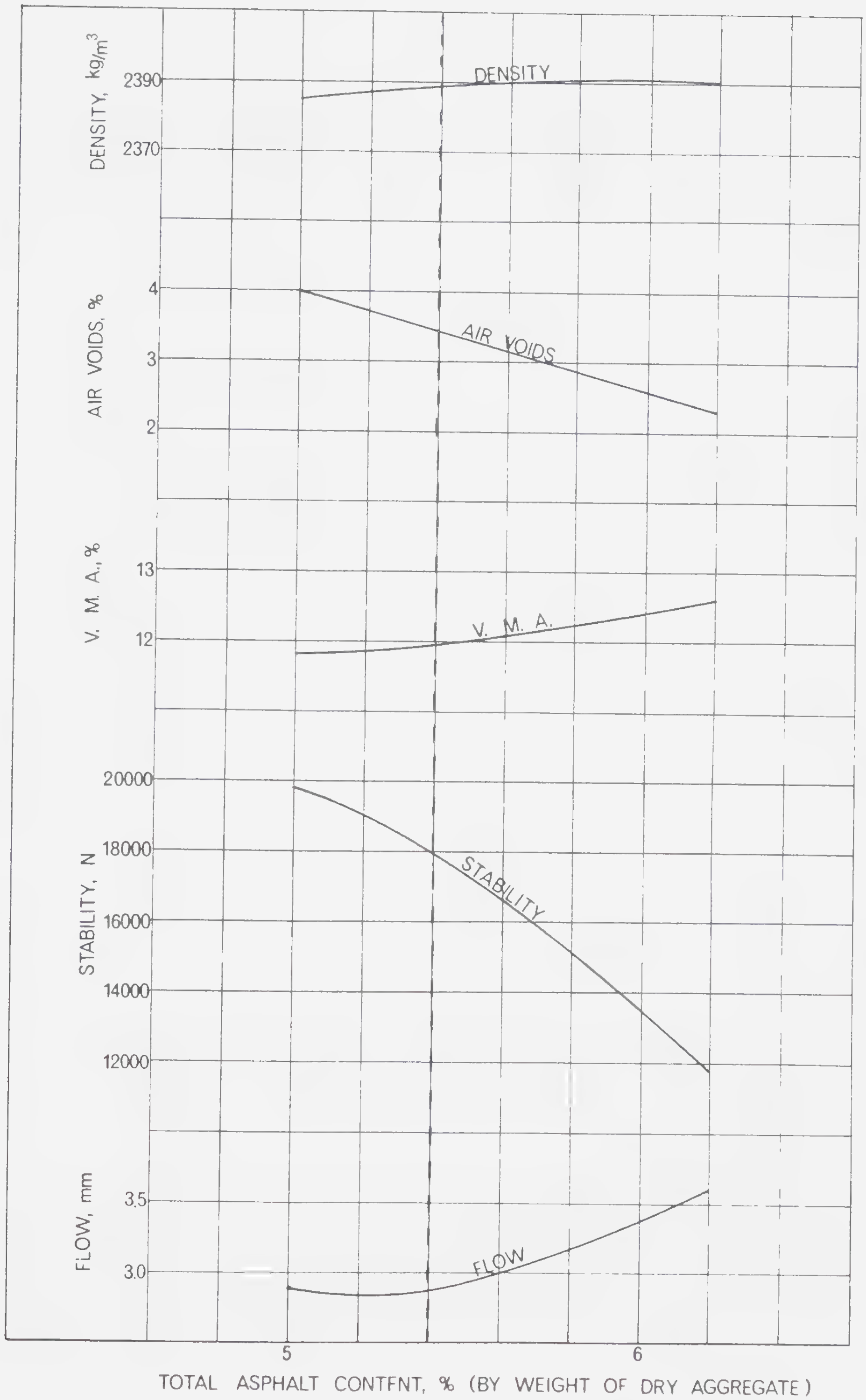


Figure 7.5 Marshall Mix Design Summary, R/V = 50/50 - Project 2:18, 2:20

3.66 m by cold milling, hauling the reclaimed material to the stockpile site, recycling the combined reclaimed and virgin material through a drum mix asphalt plant and placing the recycled mix to a depth of 50 mm as recycled asphalt pavement. This was then covered with a 60 mm lift of conventional Asphalt Concrete Pavement except for three test sections described in Section 7.5.4.

7.5.2 Reclaiming Operation

Reclaiming involved cold milling of the existing pavement to a depth of 50 mm and width of 3.66 m (12 ft).

The contractor used two CMI cold milling machines, one PR-450 Roto-Mill which had a 1.83 m (6 ft) mandrel and the other an Autograde PR-575 Roto-Mill which had a 2.74 m (9 ft) mandrel. Since only a width of 3.66 m of the existing pavement was to be cold milled, each machine milled only a 1.83 m wide strip. The two machines were operated at a close distance in the order of 50 m apart. The reclaimed asphalt pavement was loaded directly via a conveyor belt into trucks for transportation to the plant site for stockpiling. Some fine cuttings were deposited behind the Roto-Mill on the milled surface. These fine cuttings were accumulated by the sweeper and dumped in front of the cold miller. This procedure contributed to the increase in fines content of the reclaimed material.

Water was sprayed constantly in order to keep down the dust and to cool the cutting teeth.

An average of approximately 1 180 tonnes or 1.7 km of pavement was reclaimed in a 10-hour working day. The total amount of asphalt concrete reclaimed for the entire project was approximately 24 700 tonnes. Each machine milled a 1.83 m strip at a rate of approximately 5 m/minute, reclaiming about 55 tonnes/hour.

Cold milling commenced on October 1st and was completed on October 29th, 1982, a period of 21 working days. The PR-575 Roto-Mill was under repair for approximately 3 days, resulting in delays to the reclaiming and recycling operation. The air temperatures during the reclaiming operation were in the range of 0 to 20°C. The cold milling operation was slower during the colder weather with an increased rate of tooth wear. There was an observable improvement in the reclaiming operation during the warmer days.

7.5.3 Plant Operation

The hot mix plant and the stockpile for the reclaimed material were located near the Carstairs Creek Crushed Stockpile Site (SW 25-29-1-5). The aggregate from the Carstairs Creek Stockpile was used as the virgin aggregate for this project. This aggregate was hauled a distance of approximately 53 km from the Crossfield Pit to the stockpile site.

The reclaimed asphalt concrete stockpile was kept to a maximum height of about 3 meters to avoid consolidation

during warm weather and segregation. However a proper granular base for the stockpile was not built and this could have contributed to the contamination of the RAP. The conveyor belt was not used for stockpiling.

The contractor employed a 600 tonne/hour Boeing Drum Mix Plant which was not equipped with a Pyrocone to protect the reclaimed asphalt concrete from direct contact with the burner flame.

THe reclaimed asphalt concrete and the virgin aggregate were removed from the stockpile with a front end loader and placed into separate cold storage bins. From the bins both the reclaimed material and virgin aggregate were fed into the front of the drum by conveyor belt. The drum was inclined at 8.4 degrees to the horizontal. The proportioning of the reclaimed asphalt concrete and the virgin aggregate was done by the conveyor belt scales. Initially some large lumps of agglomerated materials were introduced into the drum. To prevent this a grizzly screen was installed. Lumps of both RAP and virgin materials were removed, which improved the texture of the pavement.

The new asphalt was added near the mid-point of the drum. The recycled mix was then discharged into the hot elevator at the rear of the drum and transported up into a storage silo.

Water was added to the mix at the front of the drum by means of two pipes that sprayed directly into the drum. The spray rate was controlled by a water pump and varied from

1.7 percent to 2.5 percent by weight. Water was added in order to help control stack emissions, however, the amount of dust and smoke was extremely high and definitely not acceptable environmentally. The main reason for this extraordinarily large amount of smoke undoubtedly was the lack of a Pyrocone or heat shield to protect the reclaimed asphalt concrete from direct contact with the burner flame.

The plant was operated at a production rate of approximately 280 tonnes/hour, and usually started producing recycled mix in the late afternoon. This was to allow time for the cold-milling operation to be sufficiently far ahead of the paver.

During the first half of the job the contractor did not have a thermocouple to properly monitor discharge mix temperatures. This caused very large fluctuations in mix temperatures ranging from 116 to 165°C., which is most undesirable in case of any kind of asphalt concrete mix, and especially recycled mix. The average recycled mix temperature for the first half of the job was about 143°C. For the second half of the job a thermocouple was installed and better control of mix temperatures was achieved. The corresponding average recycle mix temperature was about 148°C.

7.5.4 Paving

Paving of the recycled asphalt concrete mixture commenced on October 2nd and completed November 3rd, 1982, a

period of 21 working days. The recycled asphalt concrete was about 18 000 tonnes in total, for an average of 860 tonnes/day.

After removal of the existing asphalt concrete and cleaning of all dirt and debris from the cold-milled surface, prior to paving, a tack coat was applied using a distributor. The material used was a SS-1 emulsified asphalt.

The contractor used a Blaw-Knox PF-180H Paver for laying the mix, two Dynapac dual drum vibratory rollers CC42A and CC50A and a pneumatic tire roller for compaction. The paver screen placed the mix wider than the milled section, requiring hand raking to remove the excess. When this was not done the steel rollers were unable to properly compact the mix near the edge.

Visually, the recycled mix placed on the road did not appear very satisfactory. Some aggregate was partially coated, segregation spots were apparent and ravelling of the recycled mat began almost immediately. As seen from the compaction summary in Table 7.13, to be discussed later in Section 7.6.1, ravelling was due to inadequate compaction. Ravelling was reduced by using pneumatic tire rollers.

The low degree of compaction was one of the major problems on this project, however, this improved somewhat due to an increased compactive effort during the second half of the job. This is illustrated by the results for Units 30R, 34R and 37R. Despite the low air temperatures,

increased compactive effort resulted in densities averaging 97.5 percent compaction for these units placed on three successive days. Nevertheless, for the entire project an average compaction of 93.0 percent was obtained which was well below the specified minimum, and could not be considered satisfactory.

On November 3rd three recycled asphalt concrete test sections were placed on the top lift of the southbound inner lane. R/V ratios of 50/50, 25/75 and 15/85 were chosen for these three short test sections. A summary of the design data is presented in Tables 7.10 and 7.11.

Descriptions of these three test sections are as follows:

<u>Section 1</u> - R/V = 50/50. This section began at station 38 + 100 and ended at station 37 + 350. The virgin asphalt cement added was increased from 2.4 percent, the design value, to 2.8 percent based on observations of some uncoated aggregate. The mix temperature was about 150°C.

Numerous minor hairline cracks, segregation spots and uncoated aggregate particles were observed on this test section.

<u>Section 2</u> - R/V = 25/75. This section began at station 37 + 350 and ended at station 36 + 920. The virgin asphalt cement added was raised from 3.9 percent, the design value, to 4.1 percent again arbitrarily based on visual observations. The mix temperature was about 150°C. The recycled mat looked much better than the R/V ratio of 50/50

TABLE 7.10

Design Summary For The Three Test Sections On The Southbound Travelling Lane Highway 2:20, Top Lift

R / V		50/50	25/75	15/85
Virgin Asphalt	%	2.3	3.9	4.3
Total Asphalt	%	5.4	5.4	5.2
Density	kg/m^3	2 389	2 391	2 392
Stability	N	17 900	16 400	15 000
Air Voids	%	3.4	3.2	3.0
V. M. A.	%	12.0	12.1	11.9
Retained Stability (24 hr Soak)	%	79	80	78

GRADATION

Sieve Size µm	Percent Passing		
16 000	99	100	100
10 000	82	87	82
5 000	57	63	58
1 250	35	40	37
630	28	31	30
315	21	20	22
160	16.0	15.6	16.1
80	14.2	14.0	13.7

TABLE 7.11

Construction Summary For The Three Test Sections On

The Southbound Travelling Lane Highway 2:20, Top Lift

R / V		50/50	25/75	15/85
Unit #	%	57R	58R	59R
Virgin Asphalt Added	%	2.6	4.1	4.3
Total Asphalt Cement expected	%	5.7	5.6	5.2
Field Marshall Density	kg/m^3	2 381	2 388	2 380
Air Voids	%	3.1	3.1	3.2
Average Core Density	kg/m^3	2 224	2 158	2 175
Average Compaction	%	93.4	90.4	91.4

and all aggregates appeared coated. However, some segregation spots were still noticeable.

Section 3 - R/V = 15/85. This section began at station 36 + 920 and ended at station 36 + 250. The virgin asphalt cement added was 4.3 percent, which was the design value. The mix temperature was about 150°C. The recycled mat looked similar to the R/V ratio of 25/75. All aggregates were coated and only minor segregation spots were noticeable.

It was noticed that all three test sections were compacted to low densities, which could be attributed to inadequate compactive effort for the cool air temperatures at the time of paving.

7.6 Test Results

7.6.1 Field Laboratory Results

The results given in this section are based on the field laboratory tests obtained during construction. Tables 7.12 and 7.20 summarize these test results.

Table 7.12 shows the temperatures observed at various stages of construction. The average drop in temperature between discharge and placing, observed just behind the paver, was 11°C. with a standard deviation of 7.9°C.

Table 7.13 gives a summary of the compaction data. The average compaction achieved on this project was 93.0 percent with a standard deviation of 3.0. Figure 7.6 shows a histogram and frequency distribution of these compaction

data for the recycled asphalt pavement. According to contract specifications the asphaltic mixture should have been compacted to an average density of at least 97.0 percent and a minimum density of 95.0 percent at all locations. The achieved average compaction is about 4.0 percent lower than the specified compaction. The primary reason for the low density is insufficient compactive effort, since acceptable values were obtained on some days. Contributing factors may be the low air temperatures and high fines content which made the recycled mix difficult to compact. The large variability of the compaction results can be readily seen in Figure 7.6. The results are not normally distributed, but seem to be very erratic.

Figure 7.7 shows a histogram and frequency distribution of the compaction data for the conventional ACP used for the surface course on the same project. The average compaction is 93.2 percent with a standard deviation of 1.6 percent. These results are not as variable as those of the recycled pavement, however the average compaction is only 0.2 percent higher and well below the specified compaction.

Table 7.14 summarizes the asphalt content determinations for the reclaimed asphalt concrete and recycled mix for each production unit. The average asphalt content for RAP was 6.2 percent, based on the reflux extraction measured in the field. This is the same as previous Central Laboratory test results on cores, although the construction summary in 1970 indicated an average

TABLE 7.12

Temperature Variations For Recycled Asphalt Concrete

Project 2:18, 2:20

DATE	TIME	UNIT #	Temperature C°			
			Discharge Mix At Plant	Placing On The Road	Breakdown	Air
02-10-82	14:30	1R	144	132	120	11
	15:30	2R	139	129	120	11
	16:45	3R	139	130	118	13
04-10-82	14:05	4R	142	120	108	8
	16:45	5R	162	128	109	9
05-10-82	14:00	6R	140	130	110	10
	16:10	7R	142	135	120	10
06-10-82	15:30	9R	146	130	116	10
07-10-82	15:00	11R	132	125	120	9
	17:10	12R	146	125	118	8
08-10-82	12:30	13R	146	136	131	10
13-10-82	16:00	19R	146	136	130	18
14-10-82	17:30	22R	138	128	126	17
15-10-82	17:30	25R	140	120	110	13
19-10-82	16:15	28R	134	115	112	4
20-10-82	17:00	30R	150	120	108	3
21-10-82	16:30	34R	132	130	128	6
22-10-82	17:00	37R	130	120	115	5
23-10-82	15:00	39R	152	148	142	6
25-10-82	15:45	43R	135	-	-	7
27-10-82	18:00	48R	154	148	140	4
28-10-82	13:50	49R	155	148	142	3

TABLE 7.12

continued

DATE	TIME	UNIT #	Temperature C°			
			Discharge Mix At Plant	Placing On The Road	Breakdown	Air
29-10-82	12:30	51R	150	136	132	1
29-10-82	16:00	52R	146	140	138	8
30-10-82	11:30	53R	142	138	134	8
30-10-82	14:30	54R	142	136	132	9
02-11-82	12:50	55R	152	150	144	1
02-11-82	15:30	56R	142	140	138	1
03-11-82	15:00	57R*	150	146	144	0
03-11-82	15:00	58R*	150	142	140	1
03-11-82	15:50	59R*	152	142	142	0

* Units 57R, 58R and 59R correspond to test sections on Southbound lane.

TABLE 7.13

Compaction Summary - Project 2:18, 2:20

Date	Formed Specimen (Marshall)			Field Densities - Cores				%
	Unit #	Density kg/m³	Air Voids %	Unit #	Thickness mm	Density kg/m³	Air Voids %	Compaction
02-10-82	1R	2333	4.3	1R	--	2235	8.5	95.8
				1R	--	2026	17.2	86.8
	2R	2348	2.8	2R	--	2296	4.5	97.5
	3R	2302	4.5	3R	--	2153	11.0	93.5
				3R	--	2124	12.3	92.3
04-10-82	4R	2354	2.4	4R	--	2100	12.6	89.2
				4R	--	2095	13.2	89.0
	5R	2330	5.1	5R	--	2247	8.3	96.4
				5R	--	2197	9.5	94.3
05-10-82	6R	2361	3.0	6R	--	2143	11.7	90.8
				6R	--	2155	11.7	91.3
	7R	2345	3.2	7R	--	2241	7.4	95.6
				7R	--	2181	9.8	93.0
06-10-82	9R	2368	2.2	9R	--	2278	4.3	96.2
				9R	--	2045	15.1	86.4
07-10-82	12R	2370	3.1	12R	50	2189	10.6	92.4
				12R	50	2211	9.8	93.3
08-10-82	13R	2364	3.7	13R	--	2227	9.0	94.6
				13R	--	2199	10.1	93.4
13-10-82	19R	2382	2.8	19R	41	2223	9.0	93.6
				19R	40	2135	12.7	89.6
14-10-82	22R	2347	3.9	22R	50	2072	15.8	88.3
15-10-82	25R	2346	4.1	25R	55	2070	14.9	88.2
				25R	50	2104	13.7	89.7
19-10-82	28R	2378	3.2	28R	40	2212	9.8	93.0
				28R	45	2155	12.0	90.6
				28R	45	2145	12.4	90.2
				28R	50	2162	11.8	90.9

TABLE 7.13

Compaction Summary - Project 2:18, 2:20 - continued

Date	Formed Specimen (Marshall)			Field Densities - Cores				%
	Unit #	Density kg/m^3	Air Voids %	Unit #	Thickness mm	Density kg/m^3	Air Voids %	Compaction
20-10-82	30R	2383	2.4	30R	45	2309	5.4	96.9
				30R	35	2335	4.4	98.0
21-10-82	34R	2375	3.0	34R	55	2301	6.8	96.9
				34R	55	2318	6.2	97.3
22-10-82	37R	2380	3.5	37R	45	2302	6.8	96.7
				37R	45	2362	4.6	99.0
23-10-82	39R	2393	3.1	39R	45	2182	10.4	91.2
				39R	45	2279	6.3	95.2
				39R	45	2300	5.5	96.1
25-10-82	43R	2383	4.2	43R	50	2163	11.3	90.8
				43R	50	2267	11.5	95.1
				43R	50	2284	10.2	95.8
				43R	50	2165	11.5	90.8
27-10-82	48R	2381	5.8	48R	55	2298	9.8	96.6
				48R	55	2242	8.2	94.2
				48R	45	2128	12.7	89.4
28-10-82	49R	2386	2.5	49R	50	2322	4.6	97.3
				49R	70	2178	10.6	91.3
				49R	70	2189	10.2	91.7
29-10-82	52R	2380	2.3	52R	50	2288	6.4	96.1
				52R	50	2280	6.0	95.7
				52R	50	2323	4.4	92.6

TABLE 7.13

Compaction Summary - Project 2:18, 2:20 - continued

Date	Formed Specimen (Marshall)			Field Densities - Cores				%
	Unit #	Density kg/m^3	Air Voids %	Unit #	Thickness mm	Density kg/m^3	Air Voids %	Compac-tion
03-11-82	57R*	2379	3.2	57R	40	2214	9.3	93.1
				57R	40	2210	9.5	92.9
				57R	45	2249	7.6	94.5
03-11-82	58R*	2388	2.9	58R	70	2153	11.7	90.2
				58R	50	2150	11.9	90.0
				58R	60	2171	11.0	90.0
03-11-82	59R*	2380	2.9	59R	70	2180	11.9	91.6
				59R	45	2167	12.5	91.1
				59R	60	2179	11.9	91.6
Average		2365	3.4		50	2205	9.8	93.0
S.D.		22	0.9		8	78	3.1	3.0
No.		25	25		42	59	59	59

* Units 57R, 58R and 59R correspond to test sections on Southbound Lane

TABLE 7.14

Field Determination of Asphalt Content - Project 2:18, 2:20

Unit #	Virgin A.C. Added %	Expected * Total A.C. %	Recycled Mix A.C. %		Reclaimed Asphalt Concrete A.C. %	
			Ash Corrected † Centrifuge Ext.	Uncorrected Centrifuge Ext.	Uncorrected Centrifuge Ext.	Reflux Ext.
1R	2.3	5.4	---	5.1	---	7.0
2R	2.7	5.8	6.1	7.1	---	---
3R	2.5	5.6	---	---	---	---
4R	2.5	5.6	6.1	7.0	---	5.6
5R	2.5	5.6	5.4	6.0	---	---
6R	2.5	5.6	---	7.9	---	---
7R	2.5	5.6	5.8	7.1	---	6.0
9R	2.5	5.6	6.3	7.5	---	---
11R	2.2	5.3	5.8	6.4	7.1	---
12R	2.2	5.3	6.3	6.7	---	---
13R	2.2	5.3	---	6.3	5.6	---
19R	2.2	5.3	---	6.5	---	---
22R	2.2	5.3	---	6.5	7.3	---
25R	2.2	5.3	---	6.5	6.8	---
28R	2.2	5.3	---	6.6	---	6.0
30R	2.2	5.3	---	6.7	7.4	---
34R	2.2	5.3	---	5.5	---	---
37R	2.2	5.3	---	6.9	7.0	---
39R	2.2	5.3	5.9	7.1	7.2	---

TABLE 7.14

continued

Unit #	Virgin A.C. Added %	Expected * Total A.C. %	Recycled Mix A.C. %		Reclaimed Asphalt Concrete A.C. %	
			Ash Corrected † Centrifuge Ext.	Uncorrected Centrifuge Ext.	Uncorrected Centrifuge Ext.	Reflux Ext.
43R	2.2	5.3	---	6.6	---	6.4
49R	2.2	5.3	5.2	6.3	7.2	---
51R	2.2	5.3	5.7	6.4	---	---
52R	2.2	5.3	5.8	6.9	---	---
Average	2.3	5.4	5.8	6.6	7.0	6.2
S.D.	0.2	0.2	0.3	0.6	0.5	0.5
No.	23	23	11	22	5	5

* Expected total A.C. is the 50% reclaimed asphalt content (3.1%) plus the virgin A.C. added.

† The average ash correction for centrifuge extraction is approximately 1.0%.

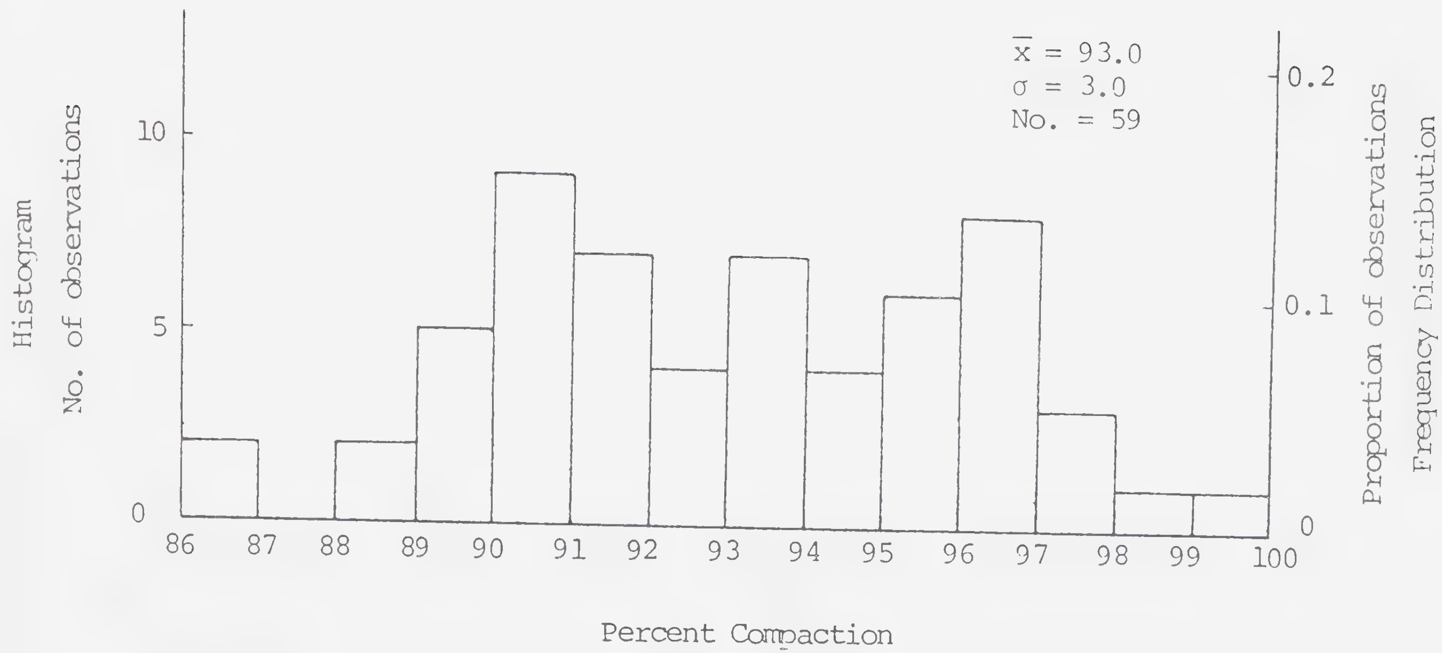


Figure 7.6 Histogram and frequency distribution of compaction data for recycled asphalt concrete. Project 2:18, 2:20.

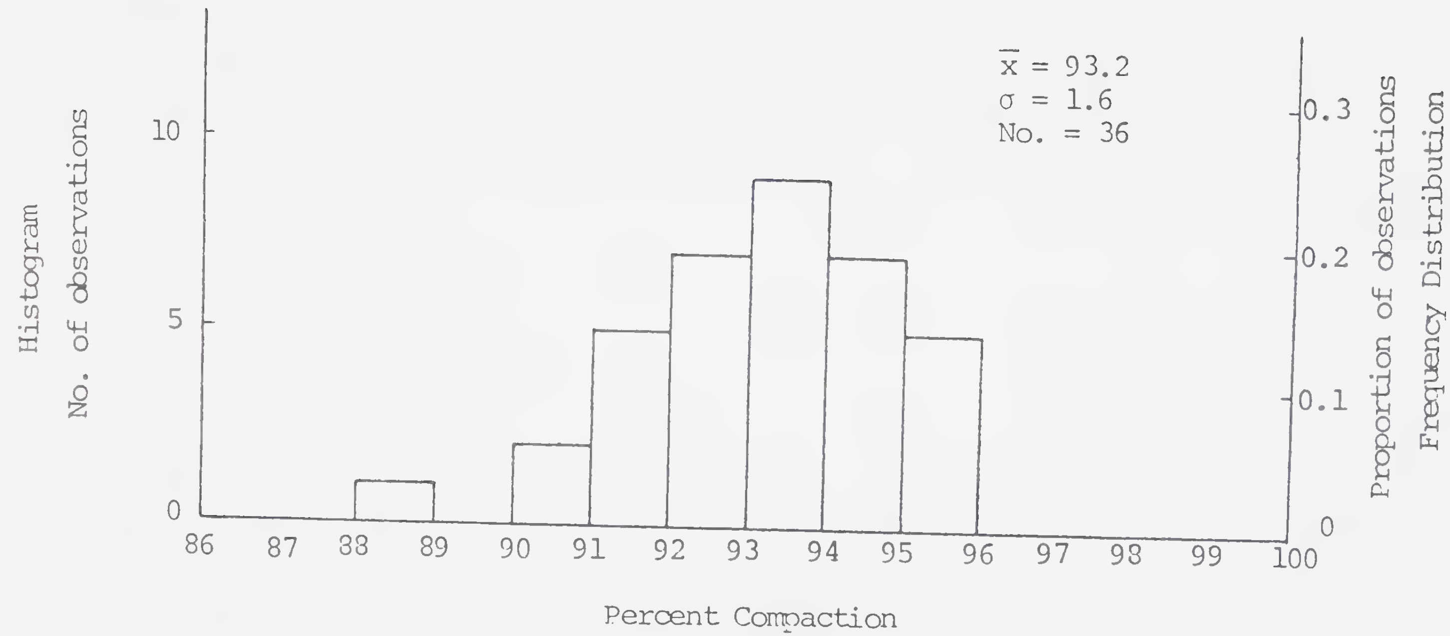


Figure 7.7 Histogram and frequency distribution of compaction data for asphalt concrete surface course. Project 2:18, 2:20.

asphalt content of 6.6 percent.

Based on the 6.2 percent reclaimed asphalt content and a R/V ratio of 50/50, the plant controls were set for an addition of 2.2 percent virgin asphalt cement. The asphalt content of the recycled mix, based on the ash corrected centrifuge results averaged higher than the optimum or expected asphalt content.

Tables 7.15 to 7.17 present gradation results for the virgin aggregate, RAP and recycled mixes respectively.

Table 7.18 gives a comparison of average gradation results for aggregate extracted from cores and cold-milled RAP. It can be seen that there has been a significant increase in the amounts passing each sieve size due to the cold milling operation. The amount passing the 5 000 μm sieve size increased by 13 percent, the 315 μm size by 3 percent and the 80 μm sieve size by 1.4 percent. It is desirable that the laboratory mix designs be based on gradation representative of the cold-milled material.

Table 7.19 gives a comparison of the theoretical and actual gradation results for the recycled mix. The theoretical gradation refers to the calculated value of 50 percent of virgin aggregate plus 50 percent of cold milled reclaimed material. It can be seen that the amount of fines has increased by approximately 1 percent through the Drum Mix plant.

Table 7.20 shows the production data for the project. Approximately 24 700 tonnes were reclaimed and 18 090 tonnes

TABLE 7.15

Gradation of Virgin Aggregate from Carstairs Creek Crushed Stockpile

Project 2:18, 2:20

Unit #	Percent Passing							Moisture Content %
	16 000 µm	10 000 µm	5 000 µm	1 250 µm	315 µm	160 µm	80 µm	
1R	100	87	63	41	21	15	11.9	4.8
4R	100	88	63	40	22	16	12.2	4.7
5R	100	89	66	42	22	16	12.6	5.9
7R	100	88	62	38	19	13	8.3	3.7
11R	100	86	65	42	19	14	11.3	6.0
13R	100	89	66	41	19	13	10.0	5.9
19R	99	80	57	34	17	12	10.1	3.2
28R	99	86	57	36	20	15	11.1	2.8
30R	100	81	52	31	17	13	9.6	3.3
37R	99	82	56	32	17	13	9.9	2.8
43R	100	91	65	41	24	17	13.7	4.7
49R	99	85	61	36	19	14	10.6	3.3
52R	99	83	58	34	19	13	9.6	3.4
54R	100	82	54	33	17	13	10.0	3.6
56R	99	81	57	35	17	12	9.8	2.5
57R	98	78	53	31	17	13	9.4	4.2
Average	100	85	60	37	19	13.9	10.6	4.1
S.D.	0.2	3.7	4.6	3.9	2.1	1.5	1.4	1.1
No.	16	16	16	16	16	16	16	16

TABLE 7.16

Gradation of Aggregate Extracted by Centrifuge Extraction from Reclaimed Asphalt Concrete**

Project 2:18, 2:20

Unit #	Percent Passing							Moisture Content %
	16 000 µm	10 000 µm	5 000 µm	1 250 µm	315 µm	160 µm	80 µm	
4R*	99	85	63	39	25	20	14.9	1.4
7R*	99	90	69	45	32	26	21.0	2.0
11R	100	93	71	44	26	19	15.0	2.2
13R	99	88	62	40	25	19	13.9	2.1
22R	99	86	61	38	27	22	17.7	1.9
25R	100	88	63	34	21	18	15.9	1.5
28R*	98	86	63	42	28	22	17.6	---
30R	99	85	64	40	24	17	12.2	3.0
37R	98	90	66	42	24	18	14.2	---
39R	98	85	64	41	24	18	13.6	---
43R*	98	90	69	46	26	19	15.4	2.1
49R	100	93	75	50	30	22	16.0	---
Average	99	88	66	42	26	20.2	15.7	2.0
S.D.	0.7	2.8	4.0	4.1	2.9	2.5	2.1	0.5
No.	13	13	13	13	13	13	13	13

* Units 4R, 7R, 28R and 43R were extracted by Reflux and the rest by centrifuge extraction.

** Reclaiming by cold milling operation

TABLE 7.17

Gradation of Aggregate Extracted by Centrifuge Extraction From Recycled Mix

Project 2:18, 2:20

Unit #	Percent Passing						
	16 000 µm	10 000 µm	5 000 µm	1 250 µm	315 µm	160 µm	80 µm
1R	100	87	62	38	25	20	15.8
2R	99	85	61	40	24	18	14.1
4R	99	89	64	40	24	18	13.4
5R	99	87	62	38	23	17	12.3
6R	99	89	68	43	23	17	13.3
7R	98	83	58	37	22	17	13.2
9R	100	88	65	42	25	18	13.1
11R	98	90	68	42	23	17	13.0
12R	100	88	65	41	23	17	13.1
13R	99	86	65	41	24	19	13.9
19R	98	86	64	40	25	20	15.8
22R	100	88	63	39	24	19	14.4
25R	99	88	64	39	24	19	15.1
28R	100	86	64	41	25	19	14.3
30R	99	92	73	48	31	24	18.8
34R	98	85	58	37	23	17	13.2
37R	99	85	60	39	23	17	13.3
39R	99	88	66	43	30	23	14.4
43R	99	87	63	39	23	17	12.9
48R	99	88	64	40	22	16	12.3
49R	98	81	56	36	21	15	11.2
51R	98	83	62	38	23	18	14.1
53R	99	88	66	42	25	18	13.0
54R	98	83	62	40	23	17	12.1
57R	95	81	60	38	24	19	14.5
Average	99	86	63	40	24	18.2	13.8
S.D.	0.2	2.7	3.5	2.5	2.2	1.9	1.5
No.	25	25	25	25	25	25	25

NOTE: Recycle Mix Moisture Content were Constant at 0.1 to 0.2%

TABLE 7.18

Comparison of the Average Gradation Results of Reclaimed Aggregate from CORES and from COLD-MILLED Material

Project 2:18, 2:20

Sieve Size µm	Percent Passing			
	Reclaimed Aggregate (CORES)		Reclaimed Aggregate (COLD-MILLED)	
	Ave.	S.D.	Ave.	S.D.
16 000	96	1.3	99	0.7
10 000	77	3.6	88	2.8
5 000	53	3.5	66	4.0
1 250	36	2.8	42	4.1
315	23	2.2	26	2.9
160	17.9	1.8	20.2	2.5
80	14.3	1.5	15.7	2.1

TABLE 7.19

Comparison of Theoretical and Actual Average Gradation

Results of Recycled Mix @ R/V = 50/50

Project 2:18, 2:20

Sieve Size µm	Ave. Percent Passing	
	Recycled Mix @ R/V = 50/50 PLANT*	Recycled Mix @ R/V = 50/50 THEORETICAL**
16 000	99	99
10 000	86	87
5 000	63	63
1 250	40	40
315	24	23
160	18.2	17.1
80	13.8	13.2

* Boeing 600 Drum Mix Plant.

** Calculated value of 50% of virgin aggregate gradation plus 50% of cold-milled reclaimed gradation.

TABLE 7.20

Production Data - Project 2:18, 2:20

Date	Reclaimed Asphalt Concrete Tonne	Recycled Asphalt Concrete Tonne	Recycled Asphalt Concrete Km.
01-10-82	1 032.60	-------	-------
02-10-82	761.50	647.45	1.630
04-10-82	971.45	796.65	1.990
05-10-82	1 200.70	880.00	2.450
06-10-82	1 160.15	614.05	1.550
07-10-82	1 290.30	863.85	1.400
08-10-82	609.80	1 138.05	2.850
12-10-82	1 143.45	-------	-------
13-10-82	1 381.60	896.60	2.350
14-10-82	2 643.70	347.75	0.960
15-10-82	1 182.75	523.50	1.260
19-10-82	755.80	624.85	1.500
20-10-82	719.75	599.55	1.900
21-10-82	643.90	602.95	1.400
22-10-82	495.80	391.85	1.150
23-10-82	734.70	562.70	1.250
25-10-82	1 533.90	994.50	2.350
26-10-82	1 628.50	-------	-------
27-10-82	1 849.05	584.40	2.000
28-10-82	2 112.70	558.75	1.100
29-10-82	911.10	1 757.65	1.870
30-10-82	-------	2 015.80	L.C.*
02-11-82	-------	1 416.95	L.C.*
03-11-82	-------	1 272.20	1.850
Total	24 682.90**	18 090.05†	32.810 #

* L.C. stands for Levelling Course.

** The total reclaimed asphalt concrete includes 9 149.0 tonnes of reclaimed material from the overlay sections.

† The total recycled asphalt concrete includes the top lift laid on Southbound travelling lane on Nov. 3rd and the levelling course applied on Oct. 30th and Nov. 2nd.

\# The total length of recycled asphalt concrete pavement includes 1.85 km of top lift on the Southbound travelling lane.

of recycled mix were produced. In addition an unknown amount of recycled mix was produced and used for the levelling course occasionally. Almost 33 km of recycled mix was placed, including the trial sections of surface course.

7.6.2 Central Laboratory Testing

The following Tables present the test results obtained at the Central Laboratory of Alberta Transportation Testing Services in Edmonton.

Tables 7.21 to 7.23 show the recovered asphalt properties for the reclaimed, recycled and virgin asphalt concrete for the project. The tests performed on the recovered asphalt cement included absolute viscosity at 60°C, Kinematic viscosity at 135°C and penetration at 25°C. The average values have been recalculated after excluding some obviously invalid data reported by the Central Laboratory on their summary. The comments made in Section 6.7.2 regarding incomplete removal of extraction solvent also apply to these results.

Table 7.21 gives the recovered asphalt properties of the RAP. Comparing these results with those reported on the cores in Table 7.5, the penetration at 25°C is slightly lower, however the absolute viscosity at 60°C is significantly higher.

Table 7.22 gives the recovered asphalt properties for the recycled mix . The penetration at 25°C is lower and the absolute viscosity at 60°C is higher than that based on

TABLE 7.21

Recovered Asphalt Properties of Reclaimed Pavement

Project 2:18, 2:20

Unit #	Asphalt Content %	Tests on Recovered Asphalt		
		Absolute Viscosity at 60°C Pa.S	Kinematic Viscosity at 135°C mm^2/S	Penetration at 25°C dmm
7R	6.1	123.8	317	131
11R	6.5	89.4	325	218
22R	7.3	20.4*	158*	325+
25R	7.2	177.0	394	108
28R	6.5	30.2*	187*	305+
30R	6.9	12.7*	126*	320+
37R	6.7	50.8	245	230
39R	7.3	89.8	323	143
43R	6.6	12.0*	143*	300+
49R	7.0	39.2*	219*	295+
Average	6.8	106.2	321	166
S.D.	0.4	42.3	47	55
No.	10	5	5	5

* Data excluded from average

TABLE 7.22

Recovered Asphalt Properties of Recycled Mix
Project 2:18, 2:20

Unit #	Asphalt Content	Tests on Recovered Asphalt		
		Absolute Viscosity At 60°C Pa.S	Kinematic Viscosity At 135°C mm^2/S	Penetration At 25°C dmm
7R	6.0	101.4	303	140
11R	5.5	14.6*	144*	too soft
22R	5.5	40.7*	216*	248+*
25R	5.5	6.0*	139*	too soft
28R	5.4	74.4	303	177
30R	6.4	100.8	315	140
37R	6.3	193.3	420	90
39R	6.7	38.9*	229*	267+*
43R	5.7	93.2	316	147
49R	5.6	16.1	157*	too soft
Average	5.9	112.6	331	139
S.D.	0.5	41.5	45	28
No.	10	5	5	5

* Data excluded from average

TABLE 7.23

Recovered Asphalt Properties of Virgin Asphalt Concrete

Project 2:18, 2:20

Core #	Asphalt Content %	Tests on Recovered Asphalt		
		Absolute Viscosity At 60°C Pa.S	Kinematic Viscosity At 135°C mm^2/S	Penetration At 25°C dmm
1	4.9	34.8*	210*	235+
4	5.3	268.3	447	74
7	5.0	459.5	559	53
10	5.4	399.9	537	58
13	5.2	348.9	513	63
16	5.5	79.4	273	219
19	5.1	115.8	389	141
22	5.3	57.1	293	263
25	5.3	46.2*	260*	270+
28	5.2	26.5	178*	260+
Average	5.2	239.7	430	124
S.D.	0.2	161.4	107	86
No.	10	7	7	7

* Data excluded from average

asphalt recovered from core samples and blended with a virgin 150-200 A asphalt cement. Since a 120-150 A asphalt cement was used in the field, these results are close to those predicted by Figures 7.4 and 7.5. The recovered asphalt could be considered as a 120-150 A grade material.

Table 7.23 shows the recovered asphalt properties from the virgin mixes used on the top lift on the project. The average results indicate the recovered asphalt to be close to a 120-150 A grade, the same as was supplied. The penetration is within the acceptable range, however the absolute viscosity at 60°C is very high and just outside the specified limits. The fact that much of the data has been excluded from these averages, and many results indicate the recovered material to be softer than what should have been supplied, leaves this data to be questionable.

If the results for core No.'s 4,7,10 and 13 were considered to be reasonable, the average penetration at 25°C was 62 and absolute viscosity at 60°C was 369. Based on average original supply values of 131 and 94.5, respectively, the retained penetration was 47 percent and the ratio for viscosity at 60°C was 3.9. Comparable results on residues from the TFOT were 51 percent and 2.3. Previous experience would indicate that there is an excessive amount of hardening during the mixing process (34), in that this was even greater than that occurring in the TFOT.

The variability in asphalt content of the various mixes can also be seen from Tables 7.21 to 7.23. The standard

deviation for the recycled mix was 0.5 percent and 0.2 percent for the virgin mix. This larger standard deviation for the recycled mix is probably due to the variability of the RAP which had a standard deviation of 0.4 percent.

Tables 7.24 to 7.26 present the gradation of the virgin aggregate, reclaimed and recycled mixes respectively, as reported by the Central Laboratory. Increased variability in the aggregate gradation of the recycled mixes compared to virgin mixes is evident.

7.7 General Observations and Conclusions

Recycling project 2:18, 2:20 was the second recycling project in Alberta. This project was not very successful from a construction standpoint. Low compaction, resulting in early ravelling, and excessive stack emissions were the major problems involved in this project.

Many agencies in the U.S.A. have adopted regulations allowing an emission rate of particulate matter not greater than 0.04 grains per dry standard cubic foot, and less than 20 percent equivalent opacity (35). Particulate and opacity requirements specified by Alberta Environment for asphalt plants are generally a maximum of 0.2 kg particulate matter per 1000 kg of stack gases, and maximum visual emission not to exceed an opacity of 40 percent over a period of six consecutive minutes.

Since the recycled pavement surface is covered with an asphalt concrete overlay, surface evaluation will be

TABLE 7.24

Aggregate Gradation for Virgin Mix - Project 2:18, 2:20

Core #	Percent Passing								% Fracture
	16 000 µm	10 000 µm	5 000 µm	1 250 µm	630 µm	315 µm	160 µm	80 µm	
1	100	79	53	32	26	18	12.9	10.2	76
4	100	84	59	36	29	20	13.8	11.5	75
7	100	80	56	34	27	19	13.7	11.3	78
10	100	84	60	37	30	21	14.9	11.4	77
13	100	82	55	33	26	19	13.5	11.0	73
16	100	87	62	38	30	20	14.0	12.2	76
19	100	81	54	33	27	19	13.7	11.1	77
22	100	80	57	35	28	20	14.4	11.9	74
25	100	84	57	34	27	18	13.3	10.6	72
28	100	82	56	33	26	19	13.5	11.1	77
Average	100	82	57	35	28	19	13.8	11.2	76
S.D.	0.0	2.5	2.8	2.0	1.6	0.9	0.6	0.6	2.0
No.	10	10	10	10	10	10	10	10	10

TABLE 7.25

Aggregate Gradation for Cold-Milled Reclaimed Material - Project 2:18, 2:20

Unit #	Percent Passing								% Fracture
	16 000 µm	10 000 µm	5 000 µm	1 250 µm	630 µm	315 µm	160 µm	80 µm	
7R	98	87	63	39	34	28	21.9	18.9	74
11R	100	88	67	43	37	29	21.8	18.2	75
22R	100	88	66	42	36	30	22.9	20.0	81
25R	100	87	64	37	30	25	21.1	18.8	85
28R	97	85	63	42	36	28	20.9	17.5	76
30R	98	91	70	46	39	30	22.9	18.5	72
37R	98	87	62	40	33	25	19.0	16.0	77
39R	98	87	65	44	38	29	21.7	19.2	81
43R	100	86	64	42	36	29	22.2	18.8	79
49R	99	90	70	46	39	31	22.5	19.1	79
Average	99	88	65	42	36	28	21.7	18.4	78
S.D.	1.1	1.8	2.8	2.9	2.8	2.0	1.2	1.1	3.9
No.	10	10	10	10	10	10	10	10	10

TABLE 7.26

Aggregate Gradation for Recycled Mix - Project 2:18, 2:20

Unit #	Percent Passing								% Fracture
	16 000 µm	10 000 µm	5 000 µm	1 250 µm	630 µm	315 µm	160 µm	80 µm	
7R	100	85	62	41	34	26	20.2	15.9	79
11R	100	65	42	35	35	25	18.1	15.3	72
22R	100	84	61	39	32	24	17.6	13.6	75
25R	100	87	60	38	31	23	18.7	15.9	74
28R	100	82	59	38	32	23	18.0	14.3	78
30R	100	85	75	51	44	35	28.8	24.9	74
37R	100	87	64	41	34	24	18.6	15.6	79
39R	100	88	67	44	37	28	20.1	17.3	79
43R	100	85	62	40	33	25	18.4	16.1	72
49R	98	80	59	38	32	24	18.0	15.3	67
Average	100	85	63	41	34	26	19.7	16.4	75
S.D.	0.6	2.5	4.8	4.0	3.8	3.6	3.3	3.1	4.0
No.	10	10	10	10	10	10	10	10	10

difficult. However, the three test sections on the southbound travelling lane with a recycled asphalt concrete surface could give an indication of recycled pavement performance in the future.

The observations made during the course of the project, and the conclusions drawn are listed as follows:

1. The cold milling operation, using the CMI Roto-Mills, was successful in partial removal of the asphalt concrete.
2. The percentage passing all sieve sizes has been increased due to the cold milling operation compared to cores. The percent increase in passing the 80 μm sieve was 1-2 percent.
3. The amount of fines has increased by approximately 1 percent for each sieve size as the material passed through the Drum Mix plant.
4. By using a proper temperature control device, the desired mix temperature can be obtained with recycled mixes.
5. The stack emissions were extremely dark due to not using a Pyrocone. Although no tests were conducted, visual observations indicated that normal environmental regulations were not met.
6. Compaction achieved for the recycled asphalt pavement on this project average 93.0 percent with a standard deviation of 3.0 percent, which is 4.0 percent below the specified minimum. Results for the conventional ACP

surface course averaged 93.2 percent but with significantly less variability.

7. It appears that the variability in aggregate gradation and asphalt content for recycled mixtures is larger than for virgin mixtures. This increase in variability suggests that recycled asphalt concrete construction projects be continuously monitored so that mix adjustments can be made as needed.
8. Placing and compacting of recycled mixes can be accomplished using the same equipment and procedures used in conventional ACP, provided adequate care and effort is used.

8. ECONOMICS OF RECYCLING

8.1 General

One of the primary reasons to recycle is economic. Recycling offers many potential benefits. Three of the major ones are energy savings, cost reduction or savings and the conservation of natural resources.

Selection of the most appropriate rehabilitation or maintenance alternative for a particular project is largely dependent upon cost and energy consumption. The primary advantages of recycling are saving in the reuse of asphalt cement already paid for, but the savings in aggregate is also very significant. High quality aggregates in surface courses in major highways can be salvaged and reused. These advantages have always existed, but prior to the development of new technology and equipment, could not be exploited in a practical sense.

8.2 Energy

Energy consumption may become a primary factor in determining which rehabilitation method is to be used on existing pavements. Recycling can conserve substantial amounts of energy on many projects when compared to conventional rehabilitation methods.

In determining energy savings, many factors must be considered in each project including the following (36,37):

1. Amount of virgin aggregate required,

2. Virgin aggregate haul distance,
3. Amount of new asphalt cement required,
4. Asphalt cement haul distance,
5. Pavement removal method,
6. Pavement crushing method,
7. Haul distance from project to crushing and mixing plant,
8. Type of mixing plant,
9. Moisture content of reclaimed material and virgin aggregate.

When evaluating the energy input on bituminous construction, transportation and construction energy are two categories of major interest. These categories consist of the fuel used in hauling materials, and in operation of equipment used in processing materials and manufacturing the finished product. In considering recycling and alternative procedures, the difference in energy used in these categories will likely be one of the major considerations in determining relative costs. Conservation in these categories has a direct bearing on reducing costs of highway construction.

8.3 Cost

On many projects, total cost is the primary consideration in determining the type of rehabilitation procedure to use. For recycling to be selected, it must usually be the least expensive of the alternative methods. A direct way of looking at savings is to assess the

differences between the estimated cost for the alternative design which was not built and the actual contract cost for the recycling design. However, this is quite a difficult process and many different items are required to be considered.

Various recycling techniques can be used to reduce costs in rehabilitating pavements. For each project, the reduction in cost depends on the prevailing conditions.

There are many economic advantages to hot mix recycling. The asphalt cement binder and aggregates which are reused in recycled hot mixes, do not have to be paid for again. There is, however, a cost attached to reclaiming and sizing the old pavement for reuse. Furthermore, there is the cost of hauling the reclaimed material for the roadway to the plant site (38). However, in the case of haulage, it is often possible and practical to execute this as a back haul process, that is, the recycled mix is hauled out to the road from the plant site and the reclaimed materials are hauled back to the plant site on the return journey.

The saving in asphalt cement and aggregate tonnage through hot mix recycling, depends on the ratio of the reclaimed to virgin materials used. The higher the ratio of reclaimed material used, the greater the saving in asphalt cement and aggregates.

8.4 Cost Analysis of Alberta Recycling Projects

In this study, two recycling projects in Alberta are chosen for cost analysis.

Unit prices and material costs are obtained from estimate sheets used in a cost comparison prepared by Alberta Transportation personnel. A cost analysis for the projects based on initial construction costs is presented in the following sections.

8.4.1 Recycling Project No.1 Highway 2:26, 2:28

For the cost analysis of this project, two types of cost comparisons are made. The first compares the unit cost per tonne of recycled asphalt pavement to conventional asphalt pavement used for the surface and/or levelling course(s). The other compares the cost per kilometre of recycled pavement to that of levelling course.

General Information:

Total length of recycled pavement=	18.76 km
Total reclaimed asphalt concrete=	7344.15 tonnes
Total recycled asphalt concrete=	7000.79 tonnes
Virgin asphalt content used=	0.7 percent
Reclaimed pavement asphalt content=	6.0 percent
Recycling ratio R/V=	75/25

Unit Prices:

Reclaiming existing pavement	$6.96/tonne

Recycled asphalt concrete	\$6.57/tonne
Conventional asphalt concrete	\$5.43/tonne
Basic loading factor (B.L.F.)	\$0.752/tonne
Haul	\$0.155/tonne-km

Material Costs:

Asphalt cement (120-150 A)	\$250.00/tonne
Aggregate	\$2.65/tonne
Sand	\$0.392/m^3

For ease of calculations, the distance to the mid-point of project was chosen for haul. This distance was 11.596 km.

Comparison 1: Cost per tonne of recycled asphalt pavement versus conventional asphalt pavement for surface and/or levelling course(s).

Cost of 1 tonne of recycled asphalt pavement:

Reclaiming existing pavement	1x6.96=	\$6.96
B.L.F.	1x0.752=	\$0.75
Haul	1x11.596x0.115=	\$1.33
Recycled asphalt concrete	1x6.57=	\$6.57
B.L.F.	1x0.752=	\$0.75
Haul	1x11.596x0.115=	\$1.33
Asphalt Cement	0.7/100.7x250=	\$1.74
Virgin Aggregate	25/100x2.65=	\$0.66
Total cost of 1 tonne of		

recycled asphalt pavement=		$20.09

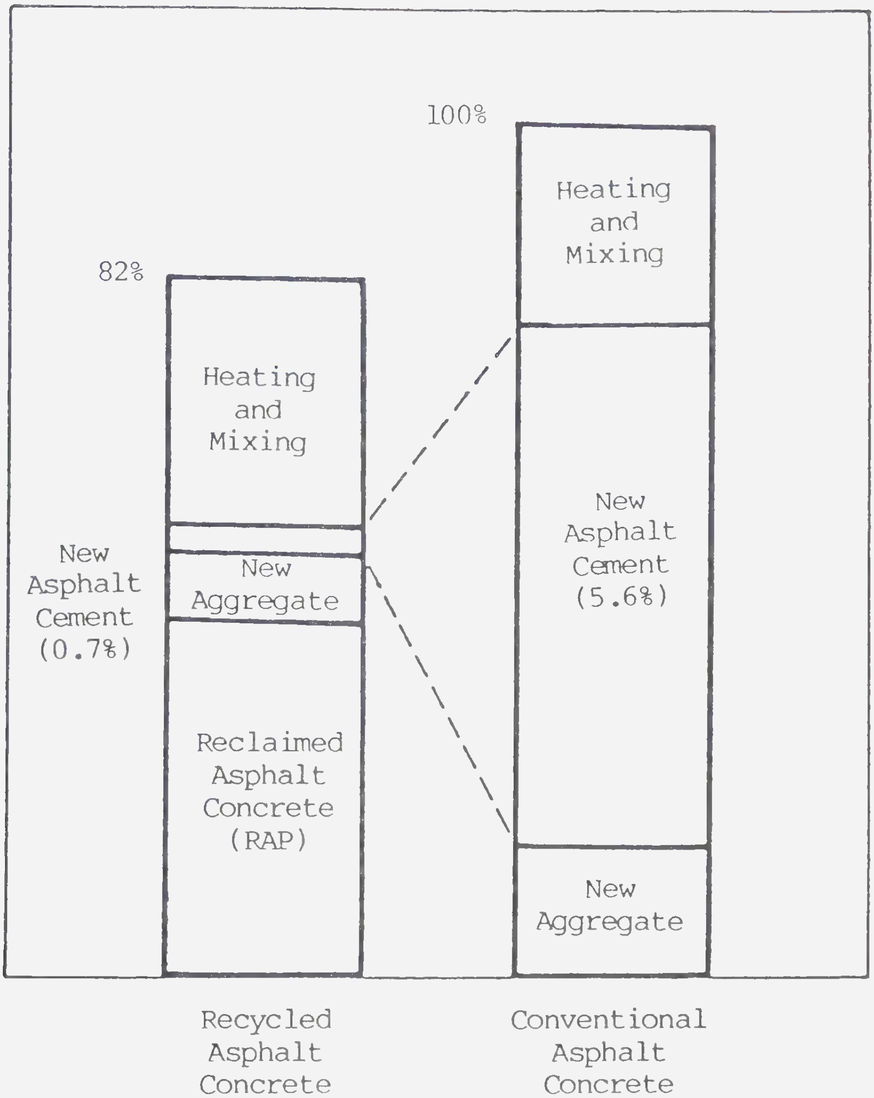
(b) Cost per tonne of conventional ACP for surface course.

Conventional asphalt concrete	1x5.430=	$5.43
B.L.F.	1x0.752=	$0.75
Haul	1x11.596x0.115=	$1.33
Asphalt cement (5.6%)	5.6/105.6x250=	$13.25
Aggregate (cost of splitting and 10% sand included)	1x3.394=	$3.39
Total cost of 1 tonne of conventional ACP= (Surface course)		$24.15

(c) Cost per tonne of conventional ACP for levelling course:

Conventional asphalt concrete	1x5.430=	$5.43
B.L.F.	1x0.752=	$0.75
Haul	1x11.596x0.115=	$1.33
Asphalt Cement (6.3%)	6.3/106.3x250=	$14.75
Aggregate	1x2.65=	$2.65
Total cost of 1 tonne of conventional ACP= (Levelling course)		$24.92

In comparing these three total costs clearly, the cost per tonne of recycled asphalt pavement is the least expensive. There is a saving of $4.06 per tonne compared to asphalt concrete surface course, and a saving of $4.83 per tonne compared to asphalt concrete levelling course. Figure 8.1 shows the graphical comparison of these costs. As could be expected the new asphalt cement is a major component of



Note: The salvage value of the 25% remaining material is not included.

Figure 8.1 Cost comparison of 1 tonne of recycled asphalt concrete pavement and 1 tonne of conventional asphalt concrete pavement. Project 2:26, 2:28.

the conventional ACP cost.

Comparison 2: Cost per km of recycled asphalt pavement versus asphalt concrete levelling course, for one-lane width.

(a) Cost per km of recycled asphalt pavement:

Recycled pavement thickness = 40 mm

Recycled pavement width = 3.66 m

Average density of recycled pavement = 2 253 kg/m^3

Total weight of recycled pavement for 1 km = 330 tonne (approx.)

Total cost of 1 tonne of recycled asphalt pavement=$20.09

Total cost of 1 km of recycled asphalt pavement

= 330 x 20.09 = $6 630

(b) Cost per km of asphalt concrete levelling course:

Average levelling course thickness = 20 mm

Levelling course width = 6.60 m (including outside shoulder)

Average levelling course density = 2 204 kg/m3

Total weight of levelling course for 1 km = 290 tonne (approx.)

Total cost of 1 tonne of levelling course = $24.92

Total cost of 1 km of asphalt concrete levelling course

= 290 x 24.92 = $7 230

These estimates show that the cost for 1 km of 40 mm of recycled pavement is less than the cost for 20 mm of

levelling course applied to the one-lane plus outside shoulder. Actual costs are dependent on thicknesses and widths used, however these estimates enable a comparison to be made for the two rehabilitation alternatives used on this project.

The salvage value of reclaimed asphalt pavement materials is equal to the value of the asphalt and aggregate less the costs to remove and haul these materials and any costs necessary to prepare them for the recycling process (39).

It should be noted that 25 percent of RAP which totalled approximately 1 840 tonnes was stockpiled and not used for this project. Therefore approximately 104 tonnes of asphalt cement, and 1 736 tonnes of aggregate remained in the stockpile. This may have an estimated value of $30 600, based on unit costs for asphalt cement and virgin aggregate. In a sense this value should be deducted from the project total cost, hence, reducing the total cost of recycling. Having deducted this value, the total cost of 1 tonne of recycled pavement reduces from $20.09 to $15.72, approximately 65 percent of conventional ACP. Similarly, the total cost of 1 km of recycled pavement reduces from $6 630 to $5 000.

In this project, a total of approximately 4 990 tonnes of aggregate and 300 tonnes of asphalt cement have been conserved by recycling.

8.4.2 Recycling Project No.2 Highway 2:18, 2:20

For the cost analysis of this project, a comparison of cost per tonne of recycled asphalt pavement to conventional asphalt pavement is made. Comparisons of the cost per kilometre have not been made due to incomplete information regarding the levelling course.

<u>General Information:</u>

Total length of recycled pavement=	32.810 km
Total reclaimed asphalt concrete=	24 682.90 tonnes
Total recycled asphalt concrete=	18 090.05 tonnes
Virgin asphalt content used=	2.3 percent
Reclaimed pavement asphalt content=	6.2 percent
Recycling ratio R/V=	50/50

<u>Unit Prices:</u>

Reclaiming existing pavement=	3.00/tonne
Recycled asphalt concrete=	$9.63/tonne
Conventional asphalt concrete=	$9.34/tonne
Basic loading factor (B.L.F.)=	$0.73/tonne
Haul=	$0.11/tonne-km

<u>Material Costs:</u>

Asphalt cement=	$246.59/tonne
Aggregate=	$1.69/tonne

For the ease of calculations, the distance to mid-point of project, which was 3.210 km, was chosen for haul determinations. The virgin aggregate was hauled a distance of 53.05 km from the Crossfield Pit to the plant site.

(a) Cost per tonne of recycled asphalt pavement:

Reclaiming existing pavement	1x3.00=	$3.00
B.L.F.	1x0.730=	$0.73
Haul	1x3.210x0.11=	$0.35
Aggregate (50%)	0.5x1.69=	$0.85
B.L.F.	0.5x0.73=	$0.37
Haul	0.5x53.05x0.11=	$2.92
Recycled asphalt concrete	1x9.65=	$9.65
B.L.F.	1x0.73	$0.73
Haul	1x3.210x0.11=	$0.35
Asphalt cement (120-150 A)	2.3/102.3x246.59=	$5.54
Total cost of 1 tonne of recycled asphalt pavement=		$24.49

b) Cost per tonne of conventional ACP for surface course:

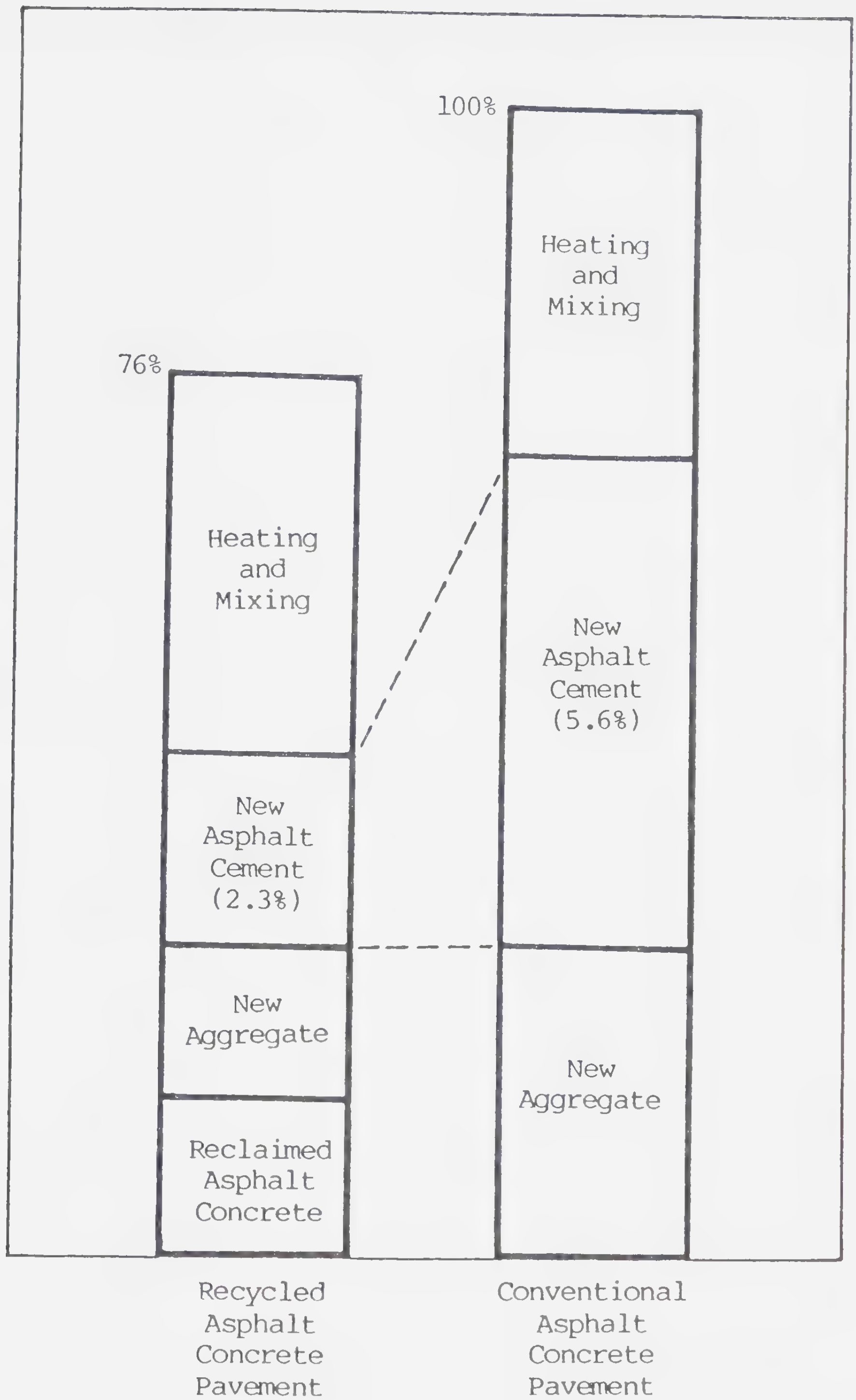
Aggregate	1x1.69=	$1.69
B.L.F.	1x0.73=	$0.73
Haul	1x53.047x0.11=	$5.84
Conventional asphalt concrete	1x9.34=	$9.34
B.L.F.	1x0.73	$0.73

Haul	1x3.210x0.11=	\$0.35
Asphalt cement (120-150 A)	5.6/105.6x246.59=	\$13.08
Total cost of 1 tonne of conventional ACP=		\$32.76

By comparing these two costs it can be seen that the cost of 1 tonne of recycled asphalt pavement is less expensive than that of conventional ACP. There is a saving of \$7.27 per tonne using recycling. Figure 8.2 shows the graphical comparison of costs.

It should be noted that only 50 percent of the reclaimed materials used in the recycling project, and an amount of approximately 9 045 tonnes left in the stockpile or used for other purposes. Therefore approximately 528 tonnes of asphalt cement, and 8 517 tonnes of aggregate remained, which may have an estimated value of \$144 590. This value may be deducted from the recycling project total cost. Having done that, the total cost of 1 tonne of recycled asphalt pavement reduces from \$24.49 to \$16.50, approximately 52 percent of conventional ACP.

In this project, a total of approximately 8 582 tonnes of aggregate and 520 tonnes of asphalt cement have been conserved by recycling.



Note: The salvage value of the 50% remaining reclaimed materials is not included.

Figure 8.2 Cost comparison of 1 tonne of recycled asphalt concrete pavement and 1 tonne of conventional asphalt concrete pavement. Project 2:18, 2:20.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The purpose of this research was to investigate the application of asphalt concrete recycling and to propose improved design and construction techniques and recommendations. The findings of this study indicates that pavement recycling can be the most desirable and cost effective pavement rehabilitation alternative.

The two Alberta recycling projects conducted in 1982 confirm that pavement recycling is a viable construction procedure requiring proper care and effort in design and construction. Evidence indicate that the future in recycling will yield tremendous savings in energy and natural resources, without sacrificing quality in pavement strength or design.

The following conclusions are drawn from the results of laboratory and field construction data, visual observations during the course of construction of the two recycling projects, and the review of the existing literature.

1. Partial width and depth removal of asphalt concrete pavements can be accomplished with cold milling equipment operating on divided highways carrying large volumes of traffic.
2. The reclaimed asphalt concrete material (RAP) can be used without further crushing, provided that it is properly handled and stockpiled. Conveyor belts may not

be used in stockpiling the RAP, however, screens to prevent oversize particles from being introduced into the drum mix plant are necessary.

3. Cold milling results in degradation of the reclaimed aggregate. Comparing extracted aggregate gradations of RAP with core samples shows an increase in amounts passing all sieve sizes. Average increases on the 5 000 μm sieve were 13 percent, on the 315 μm size 3 to 6 percent and passing the 80 μm sieve approximately 1 to 2 percent.
4. Preliminary laboratory mix designs based on cores are possible, however it is desirable that actual aggregate gradations of the RAP be available for use in designs.
5. Increased variability in aggregate gradation of recycled mixes compared to conventional mixes is evident. This is basically due to the nonuniformity of the reclaimed materials.
6. Average compaction results for the two recycled asphalt pavement projects did not meet the required specifications. However, individual results showed that the specified density requirement could be met, if adequate compactive effort is used. Compaction results for the conventional ACP surface course were similar to the recycled mixes for both projects. Hence with proper compaction equipment and adequate effort the specified density for recycled pavement can be achieved.
7. The variability in compaction results is greater for the

recycled asphalt pavements compared to conventional ACP, on both projects. This is particularly evident for the recycled asphalt pavement on the second project.

8. Operating Boeing-type Drum Mix Plants without a Pyrocone, or some other direct heat protective device, at R/V ratios as low as 50/50 produces excessive stack emissions that would not meet normal environmental regulations.
9. Comparative average costs per tonne in place show that recycled asphalt pavement is 18 to 24 percent less than conventional ACP, depending on the recycling ratio and many other factors particular to each project. If salvage values are assigned to the RAP not used for recycling on these projects, further savings can be shown.
10. Comparative estimated costs per kilometer on the first project show that 40 mm of recycled asphalt pavement, one lane in width, is less expensive than 20 mm of levelling course applied to one lane plus the outside shoulder.
11. Approximately 13 570 tonnes of aggregate and 820 tonnes of asphalt cement have been conserved by recycling on these two projects.

9.2 Recommendations

Recommendations arising from this investigation, based on existing literature and experience gained from the two Alberta recycling projects, are listed as follows:

1. Recycling projects should not be designed for R/V ratios in excess of 75/25.
2. Preliminary mix designs based on cores should be adjusted as soon as possible when reclaimed materials become available. It is desirable that the actual RAP be used for the job mix design.
3. Tighter controls are needed in the field on recycled mixtures to overcome the inherent variability associated with the process. The mixing process requires continous inspection and attention to improve uniformity and quality.
4. The cold-milled surface should be dry and properly swept free of any loose material prior to application of the tack coat.
5. If there is an excess amount of fine materials in the virgin or reclaimed aggregate, dumping of the fine cuttings in front of the cold miller by the mobile sweeper should be avoided. However, the cold-milled surface should be properly swept.
6. The plant should be equipped with a specially designed Pyrocone or some other device to protect the reclaimed asphalt concrete from direct contact with the burner flame.

7. Stack emissions should be monitored periodically during recycling operations in order that plant operating parameters be developed which would assist in meeting environmental requirements.
8. In any recycling project the mix temperature should be carefully controlled by using a proper temperature control device, otherwise large fluctuations in mix temperatures can be expected.
9. Due to the rapid loss of heat of recycled material the rollers should follow the paver as closely as possible.
10. Pneumatic tire rollers should be used on recycling projects, particularly when partial width removal is done. This helps to increase the compaction in the vicinity of the joint line of the existing pavement and the newly placed mix.
11. Recycling projects are best done during the warm seasons, since the cold milling operation is faster and paving in warm weather is more desirable.
12. Periodic evaluations of performance of the recycled pavement should be undertaken.

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